United States Department of Agriculture

Forest Service

Rocky Mountain Forest and Range Experiment Station

Fort Collins, Colorado 80526

General Technical Report RM-177

An Analysis of the Water Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Richard W. Guldin

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
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September 1989

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ACKNOWLEDGMENTS

A decade has passed since publication of *The Nation's Water Resources: 1975–2000* by the Water Resources Council. The 1979 RPA Assessment and the 1984 Assessment Update drew heavily upon that report. But because data for the former report are now 15 years old, new data and new projections were needed for this report. Water resource literature has expanded tremendously in the past 15 years, due largely to the proliferation of research and reports in response to the Clean Water Act. Susan Johnson reviewed more than 1000 abstracts and screened hundreds of publications for this report. Without her help, this report could not have been written.

Wayne Solley, Geological Survey, provided data that was essential for making projections of water withdrawals and consumption.

Several people reviewed part or all of the manuscript. These include Peter Avers, James Brown, Richard Cline, David Darr, Richard Domingue, Arthur Flickinger, Kenneth Frederick, Jack Frost, James Gregory, Thomas Hamilton, Warren Harper, Adrian Haught, Fred Kaiser, Kermit Larson, Robert Moulton, John Nordin, Dean Rasmuson, Gray Reynolds, Larry Schmidt, Rhey Solomon, Gordon Stuart, Benee Swindel, and Clive Walker. They helped prevent many errors of omission and commission.

In spite of all this assistance, perfection remains elusive. I alone am responsible for the errors that remain.

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CHAPTER 1: OVERVIEW

INTRODUCTION

Several Federal agencies have historically had responsibilities for conducting assessments of the Nation's water resources. The U.S. Geological Survey (USGS), U.S. Army Corps of Engineers, U.S. Department of Agriculture's Soil Conservation Service (SCS), and U.S. Environmental Protection Agency (EPA) and its predecessor agencies, among others, have conducted studies assessing the current situation and future prospects for water in particular regions of the country.

Responsibility for national water assessments was assigned to the U.S. Water Resources Council (WRC) by the Water Resources Planning Act of 1965. With the demise of the WRC in 1981, several member agencies have attempted to take over parts of the WRC role and improve their own analyses. USGS began to publish an annual National Water Summary in 1984. The first three annual reports, Water-Supply Papers 2250 (USGS 1984), 2275 (USGS 1985), and 2300 (USGS 1986), have been used extensively in the preparation of this Assessment. In some cases, extended portions of text have been lifted from those reports; in other cases, topics are presented in the same order. The 1986 Summary (USGS 1988) was published after preparation of this report was completed. Similarly, EPA publishes biennial reports to Congress on the National Water Quality Inventory. Information from these reports has also been extracted for this Assessment.

The Forests and Rangelands Renewable Resources Planning Act of 1974 (88 Stat. 476, as amended; 16 U.S.C. 1601–1614) (RPA) directs the Secretary of Agriculture to conduct an assessment of the Nation's forest and rangeland resource situation covering all renewable resources within the purview of the Forest Service. Water is one of the renewable resources. RPA legislation also directed the Forest Service to follow two principles in conducting assessments. First, assessments were to analyze the resource situation from a national perspective—including all ownerships, public and private. Second, the Forest Service was to use, to the extent practicable, information collected by other public agencies on the resources studied. This report faithfully follows that direction.

This report has nine chapters beginning with a broad overview of the current water resource situation in the United States. The extensive reference citations are a "road map" directing readers to more detailed discussions of individual topics in the reports of other agencies.

One requirement of the RPA legislation is an analysis, looking 50 years into the future, of prospective demands and supplies of each resource. Chapter 3 contains an analysis of historical trends in withdrawals and consumption and projections to 2040 based on data from USGS and SCS. In this report, withdrawals and consumption are treated as two different forms of demand for water. Both forms of demand are projected independently of supplies. Consumption is used in later chapters as the preferred definition of demand. Chapter 4 contains an analysis of historical trends in water supplies and projections to 2040 based upon generalized water budgets. The projections of demand and supply are the results of new analyses by the author. It is important to recognize that trends projected in these chapters are not in any sense "most likely." Rather, they portray what might occur if factors determining water resource management and use continue unchanged from those in effect since 1970. Obviously, projections of past trends will demonstrate conflicts between the level of consumptive use demanded and the level of supply projected to be available. A discussion of those conflicts is presented in Chapter 5 and the social, environmental, and economic implications of those conflicts is presented in Chapter 6. Chapters 5 and 6 also contain analyses of some alternative future scenarios for water resources having the potential to alter the demand and supply projections which were based upon recent trends.

Although projections of consumption demands and available supplies differ—creating either surpluses or shortages—these differences will not really occur. Rather, the economy will function and prices for water and other goods and services (such as water treatment) will change, thereby bringing supplies and demand into equilibrium. These adjustments, if not planned in advance, can lead to undesirable consequences. Water resource users and managers have opportunities to alter use and management practices inherent in the recent trends to achieve a more desirable future water resource situation. These opportunities are outlined in Chapter 7. Similarly, there are some obstacles—economic, social, environmental, institutional, and regulatory—to taking

advantage of opportunities. These obstacles are discussed in Chapter 8. Chapter 9 discusses implications of these opportunities and obstacles on Forest Service resource management and research programs, providing guidance for agency strategic planning.

HIGHLIGHTS OF THE WATER RESOURCES SITUATION: 1989–2040

CURRENT WATER RESOURCE SITUATION

The United States has abundant supplies of fresh water. The renewable water supply of the coterminous United States amounts to about 1,400 billion gallons per day (bgd). Aggregate daily withdrawals amount to 343 bgd or 25% of renewable supply. Aggregate daily consumption amounts to 93 bgd or 7% of renewable supply.

The Nation's watersheds are generally in good condition. But special attention must be given to managing the soil and vegetation on more than 70% of our watersheds to maintain or improve the quality and quantity of water flowing from them. A survey of watersheds in the U.S. revealed that 28% are in prime condition; 50% require special consideration of soil and vegetation characteristics when resource management plans are prepared; and 22% require direct capital investments to restore watershed condition to a level consistent with resource management goals. Most watersheds in prime condition are in the West; most special emphasis watersheds are in the South and North; and most watersheds requiring direct capital investments are in the North and Rocky Mountains.

There are 90 million acres of wetlands remaining in the coterminous United States, less than one half the acreage that existed 200 years ago. Wetlands losses are continuing at an alarming rate estimated at 350,000 to 500,000 acres annually. The principal reason for the continued decline in wetlands is conversion to urban, suburban, and agricultural land uses.

Concerns about water shortages in the United States arise because water supplies are unevenly distributed in relation to the regional and seasonal distribution of water demands.

Water resource development has been the preferred way of increasing water availability but future large scale developments are unlikely due to economic and environmental costs. A total of 480 million acre-feet of storage exists in the 2,654 largest reservoirs and controlled natural lakes with capacities greater than 5000 acre-feet; fifty thousand smaller reservoirs exist and have capacities between 50 and 5000 acre-feet. In addition, there are 2 million smaller ponds.

Other methods of increasing water availability have been tried, such as weather modification, recycling wastewater, and reducing leaks, seepage, and evaporation. Recycling was touted in the mid-1970s as having great potential, but it is no more popular today than back then.

Acid deposition, erosion, and groundwater contamination are three important water related environmental problems. All three arise due to *externalities*—resource management actions that fail to take full account of potential disruption to ecosystems caused by pollutants.

A relative abundance of good quality surface water still exists; however, serious water-quality problems have developed in some stream reaches and some streams cannot support the full range of desired uses. Programs resulting from the 1972 Clean Water Act have made significant progress in cleaning up point-source pollution. For example, total biochemical oxygen demand declined for both municipal and industrial dischargers between 1972 and 1982 (46% and 71%, respectively). Monitoring studies have found widespread decreases in fecal coliform bacteria and lead concentrations. Phosphorus concentrations have also declined, but to a lesser extent.

Nonpoint-source pollution has become more prevalent and its importance better understood as point-source pollution has been cleaned up. Monitoring studies show widespread increases in nitrate, chloride, arsenic, and cadmium concentrations. Suspended sediment and nutrients from agricultural sources are the most damaging nonpoint-source pollutants nationally.

PROJECTED DEMANDS AND SUPPLIES

The rates of increase in demand experienced from the mid-1950s to the mid-1970s have slowed. Freshwater withdrawals in the South and Rocky Mountains increased (85 and 75% respectively) at twice the rate of increases in the North and Pacific Coast regions (42 and 37% respectively). Irrigation is both the largest withdrawal use and the largest consumptive use. Thermoelectric steam cooling withdrawals have been growing most rapidly in recent years and are now almost equivalent to irrigation, but consumption is much lower.

Shortages (the situation where demands exceed supplies) are projected by 2040 for the Lower and Upper Colorado River, Rio Grande, Great Basin, California, and Lower Mississippi River Valley. Offstream water users will find water unavailable or there will be insufficient instream flows remaining to provide good survival habitat for fish, wildlife, and other instream uses. Water surpluses exist, even in dry years, in most regions east of the Great Plains and in the Pacific Northwest.

Four common themes emerge from the analysis of projected surpluses and deficits:

1. The impetus to resolve deficits will come from a desire to mitigate adverse impacts on fish, wildlife, and recreation uses caused by low instream flows.
2. Irrigation is the predominant consumptive use in each region where deficits occur; consequently, eliminating deficits will require a reduction in projected rates of growth in irrigation water consumption.
3. Non-structural approaches, such as modifications in water rights institutions and freer functioning of water markets, will play a dominant role in solving water supply deficits.
4. Water yield augmentation by vegetation management, building snow-trapping structures, and weather

modification can help remedy small deficits. However, these techniques are unlikely to be employed as the dominant way of eliminating major regional deficits.

Water quality in 2040 will be somewhat better than current quality because nonpoint-source pollution abatement efforts are just beginning to bear fruit. But water quality will be somewhat poorer than the baseline levels for forests and rangelands because some sites will undergo short-term disturbances.

Alternative futures have been briefly analyzed. If demand for water grows faster than in recent years so that total demand is 20 percent higher than projected by 2040, deficits will emerge sooner and be more severe. If the rate of increase in demand is reduced so that total demand is 20 percent lower than projected by 2040, deficits emerge later and are not as severe. If global climate changes produce average annual temperatures 2°C warmer and precipitation is 10% lower, renewable supplies are projected to be from 5 to 40% lower, depending on the region. Deficits occur everywhere except in the Lake States and Northeast and are often severe, given projected future demands.

ENVIRONMENTAL, SOCIAL, AND ECONOMIC EFFECTS

If recent patterns of water and related land resource use continue to 2040, there will be significant adverse environmental, economic, and social implications for American society. Avoiding the adverse consequences of these implications creates an impetus for changing soil and water resource management in the near future. A continuation of recent trends will:

- Reduce fish and wildlife habitat and populations and other instream uses, such as recreation;
- Lead to increased salinity causing disruptions in local economies relying upon surface water resources for potable supplies; and those relying heavily on irrigated agriculture and the processing, sale, and transportation of irrigated crops and products;
- Lead to significant additional reductions in waterfowl populations and reduction in fishing, hunting, and other recreational benefits;
- Lead to expansion of urban and suburban areas at the expense of prime agricultural land and wetlands;
- Lead to water shortages that will cause major social impacts on local residents and their communities and increase the cost of food for humans and livestock; and
- Lead to intensive groundwater mining.

MANAGEMENT OPPORTUNITIES

Many opportunities exist for changing watershed management practices on all types and sizes of ownerships to help avoid environmental, social, and economic implications of water shortages. Only through the coordinated efforts of all landowners can the use of water and related resources reach their full potential.

Major opportunities to protect minimum instream flow levels exist through administrative controls and state water rights procedures.

Major opportunities for improving watershed condition exist through increasing emphasis on maintaining water quality through vegetation management; managing runoff timing through vegetation management, snowtrapping structures, and weather modification; increasing emphasis on improving riparian areas to keep pollutants out of streams and to provide cover for fish and wildlife; and increasing opportunities to enhance soil productivity through consideration of chemical and biological aspects of soils in addition to soil physical characteristics.

Nonstructural measures, such as zoning flood plains to restrict certain types of development, provide State and local officials with the biggest opportunity for flood damage reduction.

Silvicultural nonpoint-source pollution abatement practices are well-developed; however, many opportunities exist to educate landowners about these practices and to apply them more consistently. Opportunities include better pre-harvest planning; better planning, design, and construction of roads; less soil-disturbing techniques for harvesting, storage, and hauling procedures; closure and revegetation of temporary roads and landings not needed after harvest; and careful application of fertilizers and pesticides.

Legislative changes recently implemented in the Food Security Act of 1985 and expected increases in crop yields present major opportunities to reverse the trend in loss of wetlands.

OBSTACLES TO IMPROVING WATER RESOURCE MANAGEMENT

There is political resistance in some regions to free markets for water. Water institutions are giving high priorities to offstream uses to the detriment of instream uses such as fish and wildlife habitat and recreation.

Information that accurately assesses current watershed and stream channel conditions and capabilities on all ownerships has not been consolidated. Further, information available is often not displayed to managers in ways useful to evaluate management impacts or plan rehabilitation of watersheds in the poor condition.

Private landowners lack incentives to implement *Best Management Practices* to reduce nonpoint-source pollution.

Income and property tax laws and regulations encourage wetlands conversion. There are few incentives to encourage private landowners to manage wetlands for wildlife and recreation benefits to society.

Large-scale water yield augmentation entails significant environmental and social risks.

IMPLICATIONS FOR WATER RESOURCE MANAGEMENT

The challenge for forest and rangeland managers is to preserve the volume and *quality* of water for instream

flows that promote fish and wildlife habitat and recreation and that will also satisfy emerging municipal needs in the next century.

The role of vegetation management, snow-trapping structures, and weather modification for increasing water supplies could be reconsidered. Although these practices have been extensively researched, social acceptability of implementing them over wide areas and their role in expanding regional supplies has not been clearly decided.

Institutional barriers have been erected in many areas that prevent a market for water from emerging, or where one has emerged, that constrain it from functioning efficiently. Freer functioning of water markets can help reduce shortages.

Recent gains in agricultural productivity are going to decrease the Nation's reliance on irrigation. In addition, society's preferences for water use are changing because demographic shifts are reducing the number of agricultural voters. Consequently, municipal supplies and adequate instream flows are becoming more important to society than increased irrigation usage.

Maintaining and improving water quality will become a top priority for land managers. Because municipalities prefer to pay the costs of transporting clean water long distances instead of the cost of cleansing nearby water to potable standards, municipalities outside the traditional bailiwick of the resource manager may become vitally interested in land and water management issues.

Private landowners need education and technical and financial assistance to help them make the most of their opportunities to improve water quality, to restore and protect riparian areas, and to reduce downstream flood damages.

Long-term data is an important tool for studying complex ecological problems such as acid deposition. Background information on how the ecosystem functioned before the problem emerged is also essential to determine true effects. A system of sites for long term ecological monitoring needs to be established and monitoring begun.

Additional research is needed on cumulative effects of changes in land ownership and land management objectives as applied temporally and across a watershed.

Additional research is needed on maintaining soil productivity. Work to predict vegetation growth and harvestable outputs as a function of site characteristics is in its infancy. The nutritional needs of agricultural crops and effects of nutrition on yields are much better understood. Similar kinds of information are needed for forest and rangeland species.

CHAPTER 2: THE CURRENT WATER RESOURCE SITUATION

PRECIPITATION PATTERNS[1]

The quantity of fresh water in rivers and streams is largely a function of the amount of precipitation. Nationwide, average precipitation is about 30 inches per year; however, precipitation patterns are quite variable. Average annual precipitation ranges from a few tenths of an inch in some southwestern desert areas to nearly 400 inches on some Hawaiian islands (fig. 1). East of the Great Plains, precipitation rates average 40 inches or more. In much of the West, however, precipitation rates are generally less than 20 inches annually.

After falling, precipitation moves in two general directions—directly back into the atmosphere or to streams. About two-thirds of the precipitation that falls either evaporates directly or is taken up by plants and transpired back to the atmosphere (when both are discussed together, the term used is *evapotranspiration*). Evapotranspiration rates are influenced significantly by temperature. The remaining third either runs over the soil surface to streams—perhaps causing erosion along the way—or percolates into the soil and moves through the soil profile to streams via groundwater flows. Underground geological formations containing water are called *aquifers*. Water withdrawn from streams, rivers, lakes, and reservoirs is called surface water withdrawal. Water withdrawn from aquifers via wells is called groundwater withdrawal.

RUNOFF-PRECIPITATION RELATIONSHIPS

The land area drained by a single stream is called a *watershed*. When talking about watersheds, all soil, vegetation, topographic and other factors that combine to make an integrated ecosystem are included.

It is important to understand the relationship between the amount of precipitation falling on a watershed and the amount of water in the stream flowing out of the watershed in order to measure the effect of land management activities. The relationship is usually expressed in per-acre terms comparing precipitation and runoff. The average annual runoff is computed as the average annual stream flow volume at the bottom of a watershed divided by the number of acres in the watershed.

Runoff rates are also highly variable across the United States (fig. 2). Part of the runoff variation is due to precipitation variability.[2] Other factors such as size, duration, and frequency of storms; climate, topography and geology of the watershed; and vegetation type and

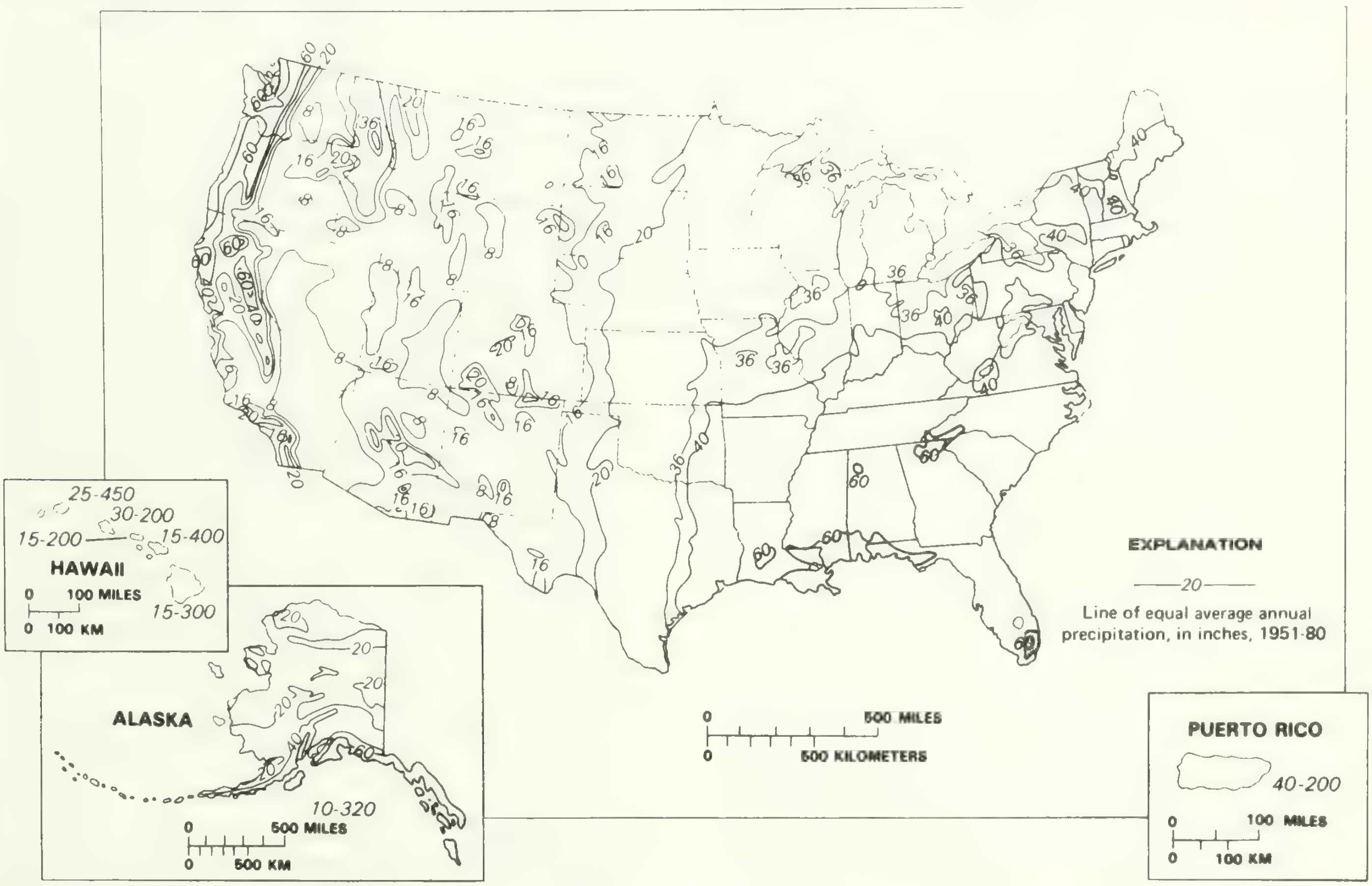


Figure 1.—Average annual precipitation in the United States and Puerto Rico, 1951–1980 (USGS 1983).

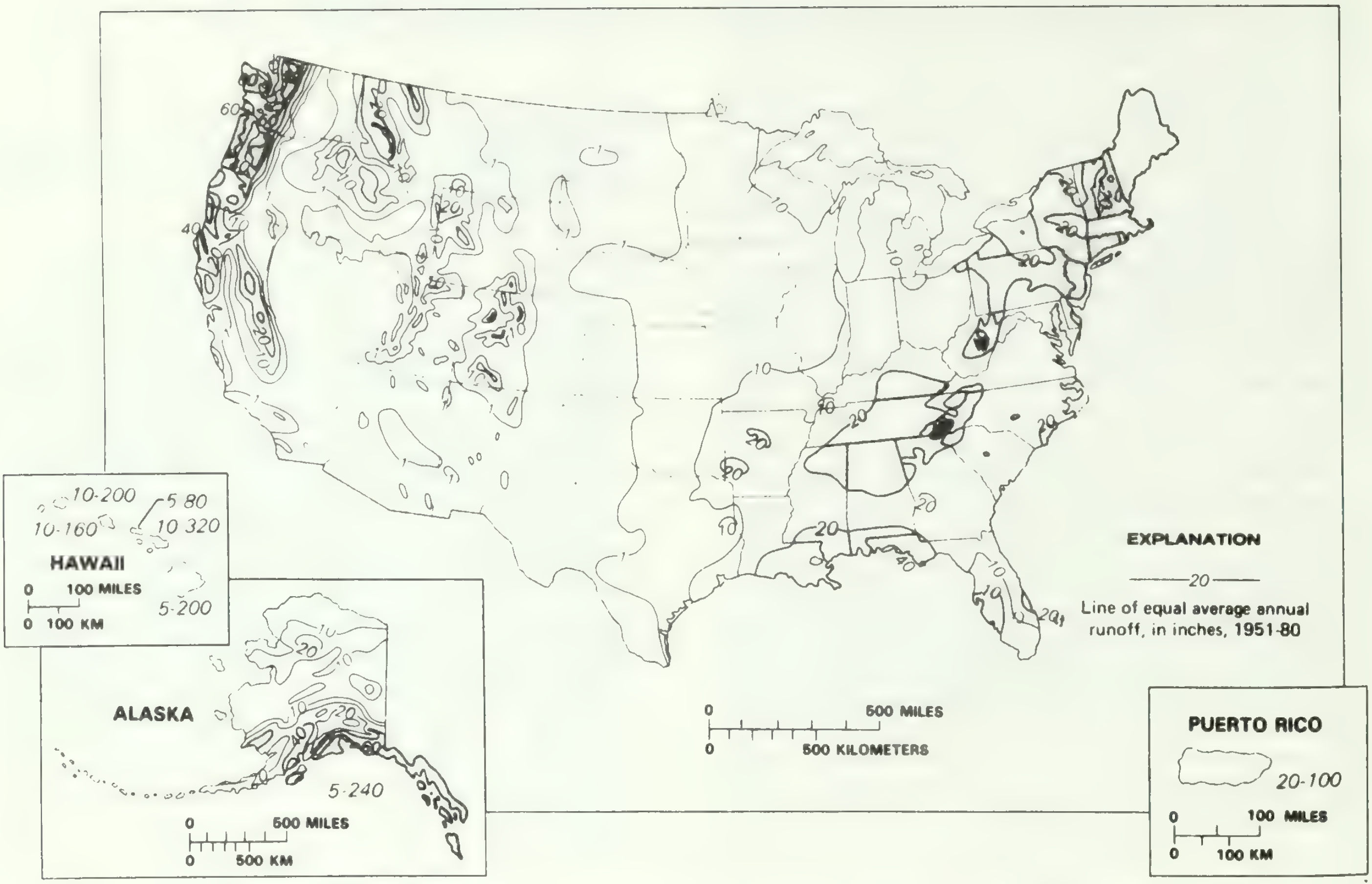


Figure 2.—Average annual runoff in the United States and Puerto Rico, 1951–1980 (USGS 1983).

distribution in the watershed also have a large bearing on runoff-precipitation relationships. The interrelationships among all these factors is what makes watershed management challenging.

Very high or very low runoff-to-precipitation relationships typically complicate managing forest and range ecosystems. High runoff-to-precipitation rates are typically associated with storms of high frequency and/or severe intensity, steep topography, and very fine or very coarse textured soils. Very low runoff-to-precipitation ratios are associated with infrequent storms or frequent ones with little rainfall per storm; storms that occur largely in summer when temperatures, evaporation, and transpiration rates are high; and with coarse textured soils or soils where high evaporation rates concentrate salts in plant root zones.

A comparison of figures 1 and 2 reveals a similarity in geographic patterns of precipitation and runoff. The highest annual runoff rates in the United States occur in Hawaii, typically exceeding 100 inches and occasionally reaching 320 inches. In southeastern Alaska and western Washington and Oregon, the annual runoff exceeds 60 inches in many watersheds. Runoff in the northern and central Rocky Mountains, the Adirondacks, and southern Appalachians exceeds 40 inches. Large areas west of the Great Plains, especially those on the east side of mountains, have runoffs of an inch or less.

Differences between precipitation and runoff are largely due to differences in evapotranspiration and groundwater recharge. Differences in evapotranspiration and recharge are due primarily to climate, topography, geology and cover.

The role of climate.—In semiarid and arid climates, most precipitation is lost to evaporation shortly after it falls. In some instances, rain can evaporate even before reaching the ground. Although potential evapotranspiration in semiarid areas may exceed 70 inches, actual evapotranspiration rates are much lower because precipitation is so scarce. Thus, actual evapotranspiration nearly equals precipitation and runoff is therefore very low. East of the Great Plains where the climate is more humid, precipitation is typically 15 to 20 inches greater than average evapotranspiration rates of between 20 to 40 inches and runoff volumes are greater.

Runoff amounts from equal annual precipitation rates vary depending on the nature of precipitation events. Given the same annual precipitation, more runoff comes from a few large storms than many small ones. Runoff is also affected by the timing of storms. Watersheds where storms are more common in summer will produce less runoff than watersheds where storms are more common in winter. The higher temperatures and more active vegetation respiration present in summer leads to more evapotranspiration than in winter.

The role of topography.—Watershed topography also affects the amount and character of runoff. A watershed with steep slopes at high elevation receiving the same precipitation as a watershed with gentler slopes at lower

elevation will produce more runoff. Steeper slopes allow water to flow more rapidly through the watershed so less time exists for evapotranspiration. Higher elevations are also associated with lower temperatures, which also decrease the rate of evapotranspiration.

Watershed topography has a significant influence on runoff because it influences the amount of precipitation received. Precipitation is usually greater at higher elevations than lower ones. Further, location of mountains relative to prevailing storm paths is another topographic factor. As an air mass crosses a mountain range, most of the precipitation falls on the side from which the storm approached. In the United States, this windward side typically faces west. The leeward side is said to be in the *rain shadow*.

The role of geology.—Geology influences runoff largely through its effect on soil texture and permeability. Runoff patterns are a direct reflection of depth, storage capacity, and permeability of soil. Coarse-textured soils encourage rapid infiltration of precipitation and rapid percolation to aquifers. Groundwater flow in such situations is relatively rapid. Fine-textured soils impede infiltration and percolation, thereby encouraging overland flow to streams. Sedimentary rock, such as limestone, generally stores more water than igneous rock. Older rock formations tend to be more fractured than younger formations, thus they store more water than younger formations. Consequently, watersheds based on relatively new igneous formations will have more runoff than watersheds based on older, more sedimentary formations.

Groundwater storage quantity is largely a function of the porosity of rock formations. Groundwater is replenished, or "recharged," by percolation of precipitation and by seepage from stream channels. Where porous rock strata intersect stream channels, water can move back and forth between streams and groundwater. Whenever stream levels are higher than groundwater levels, streams recharge an aquifer in the porous strata. When stream levels drop lower than groundwater levels, groundwater seeps into streams and becomes part of streamflow. The ability of aquifers to store runoff is so great that groundwater seeping into streams may provide an average of 40% of the annual streamflow in some areas and nearly all the flow during periods of lowest flow when direct runoff from precipitation is nil.

The role of cover.—The type of cover and its pattern on a watershed strongly influence the quantity, velocity, and timing of runoff after precipitation falls. Cover can be natural vegetation (trees, grasses, forbs), manmade (asphalt or concrete), or absent (exposed bare soil). If a large percentage of precipitation becomes runoff, little precipitation is soaking into the soil to promote plant growth and recharge groundwater. If runoff velocity is high, the likelihood of soil erosion and its concomitant loss of site productivity increase because fast-flowing water has more energy to pick up and transport soil particles. Short durations between rainfall and runoff lead to reduced likelihood of infiltration and increased stress on aquatic ecosystems and the stream channel networks receiving runoff.

Precipitation falling on a vegetated area will experience a delay in movement between falling and runoff. The surface area of living vegetation and decaying litter on a site is immense and provides significant temporary detention of precipitation. By temporarily storing some precipitation, vegetation prolongs the period of time that water can infiltrate the soil. Once infiltrated, it becomes available for uptake by roots and percolation to groundwater. Vegetation (especially roots and litter) provide texture to soil surfaces and retard runoff.

Vegetation patterns can also influence precipitation detention. For example, contour plowing and strip-cropping are excellent techniques for slowing runoff. "No-till" farming also helps conserve moisture. Manipulation of timber harvest patterns is another example. Cut areas can be designed to efficiently trap blowing snow and lengthen the period of snowmelt to allow for more infiltration and extend the period of runoff.

In contrast, precipitation falling on urban areas experiences rapid runoff from the impervious surfaces of parking lots and building roofs. Large peak flows due to extensive urbanization and rapid runoff can overwhelm stormwater conveyance systems and wastewater treatment facilities. These consequences can lead to discharge of partially treated wastewater to streams and subsequent declines in dissolved oxygen, which is harmful to fish. In estuarine systems, a massive dose of freshwater can temporarily upset the salinity balance. Nutrient cycling can also be disrupted.

Changes in land use patterns, particularly changes in cover types from forested or range to agriculture or urban uses, are an important factor in determining stream water volumes as well as the stability of aquatic ecosystems, their structure, and richness of their diversity.

Summary of roles.—Annual runoff from a watershed is the net result of all these natural influences interacting with the human influences of watershed use and management. For watersheds where natural influences predominate, the average runoff over a long period of years (to eliminate short-term climatic variations) is a reliable indicator of the long-term renewable supply of water. For watersheds where human influences predominate, mankind's effects are a much stronger determinant of the long-term renewable supply.

SEASONAL RUNOFF AND STREAMFLOW VARIATIONS

Within a given watershed, streamflows vary by season. A period of high flows is normally followed by a period of low flows. The timing of high and low flows differs by watershed location and is a function of seasonal distribution of precipitation and temperature.

Where temperatures are seldom below freezing for more than a few days at a time, the monthly distributions of runoff and streamflow volumes correspond closely to the monthly distribution of precipitation. For example, both precipitation and runoff are highest during winter in watersheds along the Pacific Coast.

Where temperatures are below freezing for extended periods, winter precipitation accumulates as snow and ice until temperatures climb above freezing and melting occurs. If snow and ice accumulate only in a limited area high in the watershed, the effect of melt water on streamflow will be minor. If only small amounts of snow and ice accumulate due to the occurrence of several freeze-thaw cycles during the winter, or if wintertime precipitation is low, little water will be stored as snow and ice, and runoff will have only a minor effect on streamflow. These are the normal situations in mountain watersheds across the United States at southerly latitudes. If wintertime precipitation is high and below-freezing temperatures occur for extended periods, then precipitation storage as snow and ice is large and the potential for a major increase in streamflow in the spring and summer is high.

The character of temperature warmup in spring after an extended period below freezing also affects streamflow variations. If the watershed is uniformly covered with snow and ice, streamflow will rise rapidly. Floods are likely in this situation. If warmup is gradual and mild, then snow and ice will melt slowly and streamflow will be higher for a longer period, albeit at a lower maximum daily flow. Flooding is less likely with this temperature scenario.

FLOW ANOMALIES

Annual variations in runoff from a watershed are caused by changes in weather patterns and precipitation. Runoff variations will be highest in arid and semiarid watersheds because a small change in precipitation has a large effect on runoff. In other watersheds, the varying intensity of storms has a large effect on streamflow. Hurricanes along the Gulf Coast can cause severe increases in streamflow.

Droughts

A drought is the prolonged and abnormal deficiency of moisture with concomitant decline in runoff to a level significantly lower than usual. The concept of moisture deficiency includes more than lack of precipitation. It also includes consideration of potential evapotranspiration, antecedent soil moisture conditions and factors influencing runoff. The effects of a drought are a function of the severity, duration, and geographic extent of the moisture deficiency; whether water supplies are drawn from streams, impoundments or aquifers; and the type and magnitude of water use.

In humid areas, a drought of a few weeks is quickly reflected in soil and vegetation moisture deficiencies. Dry-land (without irrigation) farming crop yields will decline if rain does not occur for a few consecutive weeks during the growing season. Municipal water supplies that depend on streamflow and have limited storage will not be adequate unless replenished by runoff every few weeks. Prolonged droughts rarely occur in humid areas. In more arid regions, the inhabitants protect themselves from short droughts by using stored ground or surface water. Only when these supplies run low does drought become critical in these areas. In semiarid watersheds, livestock often depend upon small reservoirs or stock ponds for water. If water users draw supplies from large rivers or major impoundments holding the equivalent of two or three years' annual flow, a critical drought is caused only by precipitation deficits that extend over several years or that are exceptionally widespread geographically. During droughts of this nature, usable water in both reservoirs and impoundments becomes progressively depleted until the usual rates of water withdrawals cannot be made.

Drought severity is often used to express the degree of adverse effects felt by vegetation, humans, and animals. Drought severity is normally expressed as a probability of a monthly low flow being attained. A streamflow drought is said to occur when streamflow for a 30-day period or longer is unusually deficient. An "80 percent" drought means that a monthly flow higher than that observed is expected every 8 of 10 years. In the water supply analysis of Chapter 3, the definition of a "dry year" is an 80% drought.

The effects of major multi-year droughts this century have been devastating. The "Dust Bowl" of the 1930s stemmed from a multi-year drought in the Great Plains. The effects of a decline in waterfowl habitat from that era are still being felt in current waterfowl populations. Other notable multi-year droughts occurred in the 1950s (Thomas et al. 1962, Nace and Pluhowski 1965) and 1970s (Matthai 1979). The years 1985–1988 have also been unusually dry in parts of the U.S.

Droughts are related to anomalous occurrences in the atmospheric circulation and solar phenomena. Droughts may occur in one part of the U.S. while another part of the country will be abnormally wet. There is as yet no agreement among meteorologists on how these abnormal atmospheric circulation patterns are generated. Some are convinced the climatic process is random. In this case, long-term accurate forecasting is impossible and the appropriate approach to the problem is through statistical probabilities. Others are convinced droughts are cyclical, so prediction involves extrapolation of historical trends to the future. In either instance, water shortages and droughts will continue to plague us. Strategies and techniques are available or are being developed that offer promise for reducing the adverse effects of droughts.

Floods

A flood is a streamflow so high that it overtops any part of a stream's natural or artificial (levee or dike) channel. Floods range from fairly common annual high flows that barely overtop natural stream banks to rare events that crest well above natural channels. Floods are usually compared according to the heights of their crest above some reference point or the probability that flows of a given size can be expected. For example, a "100-year

flood" is a flow that has a one-in-one hundred chance of being exceeded in any given year.

Floods along the coast usually result from high tides and storm surges, such as expected with a hurricane. Floods along inland streams and rivers usually result from intense rains, rapid snowmelt, or a combination of the two. The largest floods usually are caused by intense rainfall occurring in several adjoining watersheds with the runoff peaks arriving simultaneously at the confluence of tributaries from the watersheds. Flood damages are often high in such cases because towns are often located at river confluences. The second most common cause of severe floods is the combination of rapid snowmelt and heavy rainfall. Such a situation occurred in the Colorado River basin in 1984 when abnormally heavy snowpack followed by unseasonably warm temperatures caused a near-record runoff that began about May 20, 1984. Heavy rains in part of the basin led to peak flows more than 1.5 times the estimated 100-year flood level on the Uncompahgre River at Delta, CO.

Floods can also be created or exacerbated by other watershed factors. These include mountain glaciers, unstable soil and rock formations, earthquakes, volcanic activity and the presence of impoundments in combination with the above. For example, the flood resulting from the June 5, 1976 collapse of Teton Dam in the Snake River drainage, Idaho, has been attributed to porous fractured rock formations used to anchor an abutment and that underlay the dam itself.[3] Mud flows resulting from the combination of glacier melt and volcanic explosion on Mount St. Helens in 1980 caused great damage—even obstructing the shipping channel in the Columbia River 70 miles from the volcano. Even after receding, the mud left along the Toutle and lower Cowlitz Rivers so constricted the channels that even the average annual high flow could have caused severe over-bank flooding (Foxworthy and Hill 1982).

About 6% of the land area in the lower 48 states is prone to flooding. Nearly 21,000 communities have flood problems. Floods cause about 10 times more deaths each year than any other natural hazard. During 1985, the economic loss due to flooding was about $500 million—the lowest amount since 1971. Despite these losses, floods do have beneficial effects. Because a large part of the annual runoff from some streams occurs during floods, such floods play a major role in replenishing reservoirs and are important elements in water supply management.

Intensive land use has drastically modified flood plains and streamflow characteristics from their natural condition 400 years ago. It is clearly established that virtually every change in land use alters, to some extent, the water quality and flow regime of a watershed. This is especially true of use changes in the floodplain. Development typically involves placing impervious surfaces (roofs, pavements, roads) over part of the area. Runoff from these surfaces is high and fast. Thus, development tends to increase flood peaks and shorten peak duration, thereby increasing flood damages. Because of the high cost of structural flood control and attendant undesirable side effects, emphasis in flood protection has shifted to non-structural measures. These include improving flood forecasts, installing community flood warning systems, zoning or limiting land uses in flood-prone areas, and publicizing flood hazards. The USGS, the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), the National Oceanic and Atmospheric Administration (NOAA), SCS, and various state agencies have cooperated to develop and implement flood control measures.

Despite non-structural measures, the long-term trend in flood damages is increasing. Much of the increase in economic losses can be attributed to continuing encroachment of development onto the floodplain. In spite of the risk, people continue to be attracted to floodplains by advantages such as flat land, desirability for transportation routes, access to water, and superior agricultural soils. Once floodplain uses are established, governments try to control flood damages by building dikes, levees, dams, and other flood control structures. Because these structures successfully reduce damages from small to moderate floods, additional incentives exist to develop the floodplain further. Thus, when a flood occurs that overwhelms flood control structures, resulting damages are often much greater than if development had been limited by periodic, small-scale flooding.

WATERSHED CONDITION

What happens to precipitation after it falls is affected by the intensity and duration of the rainfall as well as the climate. Short, light rains in arid climates evaporate nearly completely; long intense rains during a hurricane largely become runoff. The nature and condition of soils and vegetation where precipitation falls also play an important role in the amount of precipitation that evaporates, infiltrates the soil, or runs off the site. Dense vegetation intercepts precipitation and promotes evaporation and transpiration; scattered vegetation, perhaps due to recent disturbance by fire or management practices, intercepts less water so more is available for infiltration or runoff. Sandy soils and flat topography promote infiltration; clayey soils and steep topography promote runoff.

Human influences that modify soil and vegetative patterns in watersheds alter natural watershed responses to precipitation. For example, urban development paves and erects roofs over land making it impervious to rainfall; less infiltration and more runoff is the result. Removing forest cover or plowing prairie grasslands reduces evaporation and exposes soil to the erosive influences of runoff. Because the influence of mankind's use of the land and vegetation is pervasive in many watersheds, managing soil and vegetation on the watershed is a key factor in managing the quality and quantity of water draining out of the watershed.

National Forests were originally established "...to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of the citizens of the United

States..."[4]. The central idea was to manage the forested ecosystem to maintain favorable (in terms of both quantity and quality) water flows and to maintain soil productivity to produce vegetation such as forage and trees. These goals for forest and rangeland management are embodied in the concept of *watershed condition*. Watershed condition describes the relative health of a watershed. It reflects the stewardship role of the Forest Service and is measured against management objectives in terms of factors affecting favorable conditions of flow and soil capabilities.

Maintaining favorable conditions of flow refers to behavioral characteristics of a watershed described in terms of its ability to sustain water quality, quantity, and timing necessary to support water-dependent ecosystems, instream uses, and downstream withdrawals of water. Included in this concept are managing land uses affecting water quality and quantity as well as managing the natural and manmade stream channels carrying flows to users. Also included is managing water in streams, associated fauna and groundwater flows.

Maintaining soil capability refers to the inherent capacity of a soil to support growth of specific plants, plant communities, and sequences of plant communities. Included in the concept of plant communities and the succession of communities are the associated fauna.

The concept of watershed condition provides an excellent basis for assessing the resource situation for water and related land resources. The condition of watersheds nationwide has been evaluated for this report by analyzing watersheds (40,000 to 180,000 acres in size) in each Forest Service Region. Each watershed was placed in one of three watershed condition classes described below. A regional summary was prepared describing the percentage of watersheds in each part of the United States that are in each condition class (table 1).

CLASS I: REGIMEN ATTAINMENT

Watersheds in this class provide a robust basis for sustained production of goods and services. Watershed management is such that no long-term changes are occurring even when major precipitation events occur. These watersheds represent an attainable, desirable condition. They are in dynamic equilibrium as evidenced by a stable drainage network. Response of a watershed to use is accommodated by the current channel network density, size, and process.

Table 1.—Watersheds by watershed condition class, 1987

Region	Condition Class I	II	III
	-------	*percent*	-------
North	15	60	25
South	20	67	13
Rocky Mountains	27	49	24
Pacific Coast	36	45	19
U.S. Total	28	50	22

In Class I watersheds, production of goods and services can be sustained with low risk of deterioration in watershed condition. These watersheds are most prevalent in the Pacific Coast and Rocky Mountain regions. Legislation and regulations governing use of land designated as wilderness have a major influence in keeping watersheds in Class I condition because they have proscribed many surface-disturbing uses such as off-road vehicle use and timber harvesting. Considerable roadless land not designated wilderness is in watersheds having such rugged terrain that land-disturbing activities can only occupy limited areas if they can occur at all.

CLASS II: SPECIAL EMPHASIS

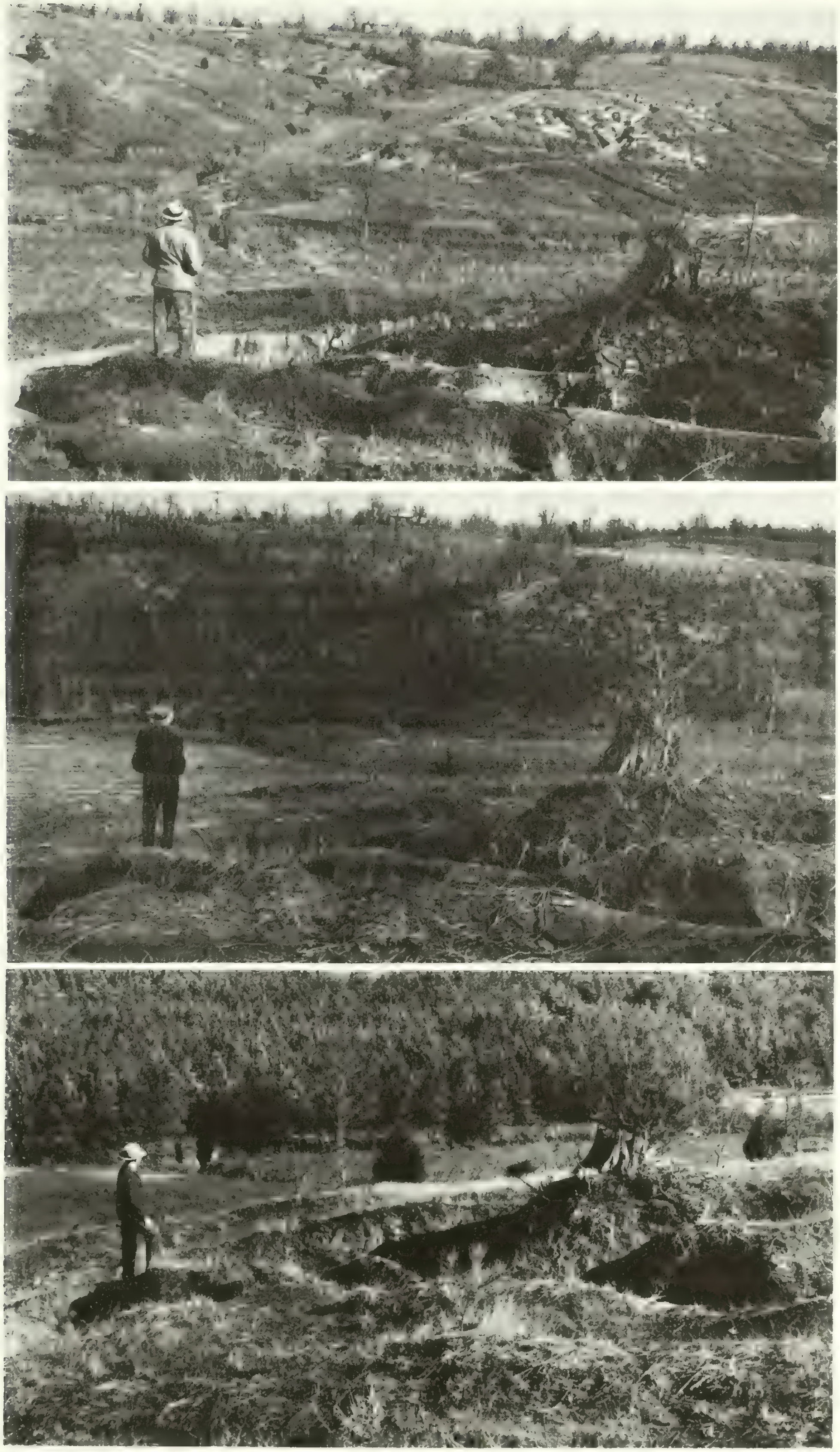
Watersheds in this class are not attaining Class I requirements but do not require capital investments to restore Class I watershed conditions.

One-half of watersheds surveyed are in Class II. Watersheds in this class require special consideration of soil and vegetation characteristics when resource management plans are prepared because soils in these watersheds have a high potential for erosion and significant risks to water quality exist. In short, improper or insensitive management may quickly lead to major soil or water problems and deterioration to Class III conditions.

Many Class II watersheds are currently performing to management objectives. There are four reasons why most watersheds are in Class II. Some are sensitive to specific land-disturbing activities such as mining, off-road vehicle driving, or timber harvesting. Other watersheds are sensitive to the cumulative effect of activities. Cumulative effects can result from activities having a light per-acre impact, but a total effect that has overwhelmed the watershed's ability to tolerate widespread use. Also in Class II are watersheds where use potential is inherently limited due to fragile soils and stream channels, and watersheds that have not reached a dynamic equilibrium in recovering from past abuses.

The South and North have the greatest number of watersheds in Class II primarily because of high water tables, severe erosion hazards, and a lower percentage of wilderness and other unroaded lands than in the Pacific Coast and Rocky Mountain regions. High water tables reduce trafficability. Lands with limited potential for maintaining favorable water flows are most common in the Rocky Mountain region; and comprise the bulk of Class II watersheds there. Watersheds in Class II in the Pacific Coast region are subject to landslide hazards, primarily in high rainfall areas. Because of steep terrain in the Rocky Mountains and Pacific Coast regions, watershed condition concerns often relate to location of transportation corridors and protection of riparian areas. Steep terrain also increases the risk to downstream areas of flooding because of rapid runoff. Therefore, any activities that disrupt infiltration and increase overland flow are of particular concern in Class II watersheds in these regions.

Factors affecting watershed condition and risks to sustaining condition vary greatly among and within a



The Yazoo-Little Tallahatchie Flood Prevention Project demonstrated how tree planting could help restore soil productivity in badly eroded watersheds. (a) Eroded field typical of many thousands of acres in northcentral Mississippi, 1948. (b) Loblolly pines were planted in 1949; four years later, the area is beginning to recover, 1953. (c) By 1957, rehabilitation of the site was well underway.

region. Because such a large proportion of watersheds are within Class II, opportunities to improve conditions through integrated resource management are greater than through direct capital investments. While both approaches cost time and money, the process of integrating resource management is often more affordable per acre. However, integrated resource management requires highly professional skills and creativity.

CLASS III: INVESTMENT EMPHASIS

Watersheds in this class require technologically and economically feasible capital investments to restore watershed conditions to a level consistent with resource management goals. Determination of feasibility must consider environmental, social, and economic desirability. Land treatments and structural measures are necessary to provide an improved watershed equilibrium, which will improve the watershed to Class II condition. In contrast, non-structural measures—integrated multiple-resource activities—are used to improve a Class II watershed to Class I status.

Nationwide, about 22% of all watersheds need capital investments to restore water quality, quantity, timing, or soil productivity to acceptable levels. This does not mean that 20% of the land area or channels are in Class III condition. A relatively small area can disrupt an entire watershed system by its contribution of sediment, mine waste, increased flow volume, or other impacts that influence soil productivity and favorable conditions of water flow.

The South has the fewest watersheds needing capital investments to restore watershed conditions to levels consistent with management goals. In other regions, between one-fifth and one-fourth of watersheds need capital investments. At the beginning of the 20th century, many watersheds across the South were badly deteriorated because of abusive farming practices in the 1800s. After agriculture was abandoned, many watersheds seeded naturally to southern pines. Reforestation restored the watershed condition to Class II in most cases.

A classic example of the kinds of capital investments necessary to restore Class II conditions is the Yazoo-Little Tallahatchie (Y-LT) Project in north-central Mississippi. Watersheds of the Yazoo and Little Tallahatchie Rivers contain highly erodible soils, many of loessal origins. By the 1930s, after being farmed for a century, soil capability to produce crops was exhausted. Due to a lack of vegetation to serve as ground cover, precipitation caused massive and widespread gully erosion. In 1946, the Forest Service and SCS began a joint rehabilitation program. The project area covered 4.2 million acres in 19 counties. Four major goals of the Y-LT Project were to reduce floodwater and sediment damages, to promote proper land use, to stabilize stream channels, and to improve the local economy in north-central Mississippi (Guttenberg and Pleasonton, 1961). In the early 1960s, it was the largest individual land and water management program in the United States.

Farm conservation plans based on land capabilities were developed with the assistance of SCS District personnel. Following approval of the conservation plans, financial assistance was provided to plug gullies and plant trees. On "critical" areas (exposed soil, slopes over 8%, gully erosion present, and downstream damage occurring), the entire cost was paid by the government. On other areas, free tree seedlings were provided and costs of planting and control of competing vegetation were shared between the government and landowner. Today, watersheds of the Yazoo and Little Tallahatchie Rivers support productive stands of southern pine with sufficient volumes to attract new wood processing industries to the north-central Mississippi town of Grenada. Some areas are currently being harvested, providing jobs and income to the local economy. Of course, harvesting must be done carefully to avoid creating new erosion and replanting is essential.

The Y-LT Project is an example of how direct capital investments can be used to rehabilitate Class III watersheds and move them to Class II conditions. Its success has been the impetus for more recent watershed rehabilitation and improvement programs, such as the Soil Bank Program of the 1950s and 1960s, and the Conservation Reserve Program of the 1980s.

SUMMARY

Watershed condition strongly influences the quantity and quality of water available for use. Current status of the Nation's watersheds is less than ideal—one-fifth need capital investments and one-half need especially careful management to attain long-term land and water resource management goals. Consequently, the quantity and quality of water currently available for use is also less than ideal.

The current situation for water use from a quantity perspective is examined next. Following that, the Nation's water quality situation is reviewed along with the wetlands situation. These discussions of rainfall and runoff volumes, watershed condition, quantity and quality of water currently used, and wetlands condition provide the necessary background to assess future demands and supplies of water as outlined in Chapters 3 and 4.

QUANTITY OF WATER AVAILABLE FOR USE

The renewable water supply of the coterminous United States amounts to about 1.4 trillion gallons per day. Even though total offstream withdrawals of surface water nearly doubled from 1960 to 1985, withdrawals still remained only 21% of the renewable supply in 1985. Despite major droughts, such as the one in the eastern United States in 1985 and 1988, and despite chronic water shortages in some localities, the nation is not "running out" of water. Periods of drought will be followed by periods of above-normal precipitation and runoff as in the past. Most concerns about water shortages arise because of uneven water distribution in relation to the

regional and seasonal distribution of water demands. Concerns also arise because of increasing demand for existing supplies and related difficulties in distribution. In some situations, changes in engineering, management, or institutional procedures can improve the situation.

Although the available supply appears unlikely to change appreciably in the near future, estimates of that supply may not be very accurate because there is no objective way of selecting a representative period of record that includes the full range of possible variations. Moreover, even if the long-term average supply could be closely estimated, the actual supply over a specific future period probably will deviate from that average. One problem facing water resource planners is the inability to define accurately the amount of water available. This uncertainty should be considered in developing and allocating water resources.

INSTREAM VERSUS OFFSTREAM USES

Water has value both instream and offstream. Instream uses of water include navigation, fish and wildlife habitat, hydropower generation, recreation activities, and dilution of wastes. Instream uses usually require some minimum flow rate, thus they compete directly with offstream uses which reduce instream flows. For example, instream flows must not fall below some minimum rate if navigation is to continue. Some instream uses can tolerate reductions below the minimum essential level for a short period of time with little or no long-term adverse effect. For example, navigation can be suspended for several weeks during exceptionally low flows and start up when sufficient water is available without incurring a significant long-term reduction in navigation benefits. Wildlife and fish habitat, on the other hand, can suffer devastating long-term losses from several weeks of abnormally low flows. Of the instream uses mentioned above, fish and wildlife habitat is the most sensitive because long-term damage results from low flows.

Offstream uses are also called diversions or withdrawals because water is withdrawn or diverted from the stream channel or pumped from the ground and transported to the point of use. Offstream uses include cooling power generators (thermoelectric steam cooling in USGS parlance), irrigation, industrial and commercial use, and potable use. For all uses except irrigation, most water is returned to the stream following use, usually with some aspect of its quality (temperature, dissolved solids, other chemical constituents, sediment load) changed. That part of the water withdrawn from the stream and not returned is "consumed", principally by vegetation which subsequently transpires it back to the atmosphere or by evaporation during use. In Chapter 3, the trends in demand for water will be discussed in terms of withdrawals and consumption by six main uses.

In parts of the country, large flows are withdrawn from watersheds and transferred by pipes or aqueducts to other watersheds where demands for withdrawals exceed available flows. For example, water from streams in central and northern California and from the Colorado River are currently transferred to southern California. Such interbasin transfers of water are equivalent to a 100% consumptive use from the perspective of the watersheds where the water originates.

Pumping groundwater is also considered an offstream withdrawal of water. Where a porous stratum containing groundwater intersects a stream bed, pumping water from the aquifer can not only intercept water that would otherwise seep into the stream channel, but if sufficiently intensive, can induce water to flow from the stream into the aquifer. Reductions in instream flows occur some time after the onset of pumping, and unless the wells are very near the stream, usually do not coincide with the times of peak withdrawals from the streams.

GROUNDWATER DEVELOPMENT[5]

The volume of groundwater in storage in the upper half-mile of the Earth's crust within the coterminous United States has been estimated to be about 50,000 cubic miles (55,000 trillion gallons). Some water is highly saline and unsuitable for most uses. The recharge, or the rate of flow through the groundwater system, is estimated to be near 1 trillion gallons per day. A large percentage of this flow moves through very shallow aquifers which discharge to streams without reaching major aquifers. Only a portion of this shallow recirculation could be recovered by wells.

The pumping rate of fresh groundwater in the United States in 1985 was approximately 83 billion gallons per day (bgd), or about 8% of the estimated daily flow through the Nation's groundwater systems. From a national perspective, the groundwater resource is not overdeveloped. However, problems do exist in many localities.

The total groundwater withdrawn in 1985 represented about 24% of the total freshwater withdrawals in the United States. The largest single use is for irrigation—slightly more than 56 bgd. Although irrigation is the largest withdrawal, roughly half the population in the United States relies upon groundwater for potable supplies. About two-thirds of the groundwater withdrawals in 1980 were concentrated in eight states: California (21 bgd); Texas (8 bgd); Nebraska (7.2 bgd); Idaho (6.3 bgd); Kansas (5.6 bgd); Arizona (4.2 bgd); Arkansas (4 bgd); and Florida (3.8 bgd). Nine states use more groundwater than surface water—Arizona, Delaware, Florida, Hawaii, Kansas, Mississippi, Nebraska, Oklahoma, and Texas.

The pumping rate for groundwater increased steadily from 1960 to 1980 (fig. 3). Some factors responsible for the increase include: 1) a significant expansion of irrigation in the humid East as well as the West, particularly through the use of center-pivot irrigation systems; 2) water supply requirements of growing urban areas, particularly in the South and Southwest; 3) water demands associated with energy production; 4) a desire to establish drought-resistant supplies; 5) objections to the construction of surface reservoirs; and 6) objections to

exporting water from one watershed to another. The quantity of groundwater withdrawals in 1985 represents the first reduction in withdrawals reported in the past 3 decades. The 10% reduction is more than a data anomaly—it reflects some changes in factors contributing to the increase since 1960.

Aquifer Declines

Aquifer declines have occurred in many areas since development began. But not all declines are of major concern. In most areas, declines occurred at depths substantially deeper than the water table. But because of artesian processes involved, declines do not represent the loss of large quantities of water from storage.

In some areas, however, declines are serious. For the High Plains region of Kansas, New Mexico, Oklahoma, and Texas, and for the alluvial watersheds of southern Arizona, aquifer declines resulted in a significant lowering of the water table. In these areas, very large volumes of water have been withdrawn, and continue to be withdrawn from storage. In some parts of central California, substantial withdrawals of groundwater in local areas have largely dewatered porous strata, leading to compaction of the strata and surface land subsidence. A description follows of the situation's severity in the four areas most heavily affected.

The High Plains

The High Plains encompass 174,000 square miles in northwestern Texas, the Oklahoma panhandle, western Kansas, Nebraska, and the eastern fringes of Wyoming, Colorado, and New Mexico. A rapid expansion in groundwater withdrawals for irrigation began in the southern High Plains in the early 1940s. Irrigation spread to the middle High Plains in the 1950s and to the northern High Plains in the 1960s. As irrigation spread, so did groundwater withdrawals. In 1949, about 2 million acres in the High Plains were irrigated by 1,303 billion gallons.

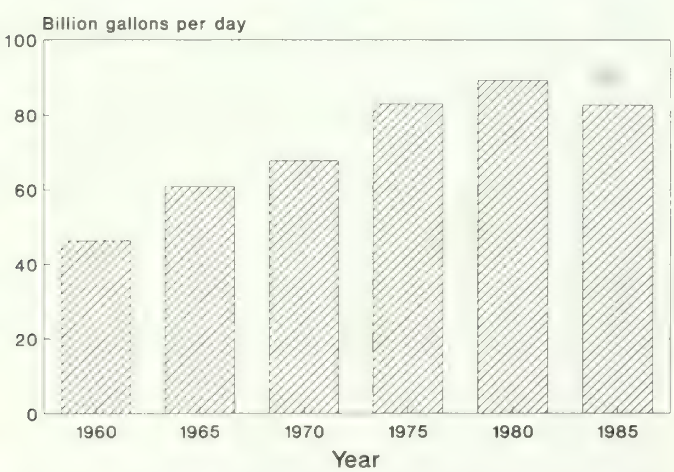


Figure 3.—Trends in groundwater withdrawals in the United States, 1960-1985.

By 1980, 5,865 billion gallons were pumped to irrigate 13 million acres.

Between 1940 and 1980, 68.4 trillion gallons of groundwater were withdrawn for irrigation in the southern High Plains. It is estimated that 43% of this volume was water from storage, 45% was recycled irrigation water percolating back to groundwater, and the remaining 12% was groundwater diverted from two sources as water tables dropped. The sources were groundwater that would otherwise have drained into streams and additional groundwater entering aquifers from streams. Floods in the early 1970s contributed significantly to recharge.

Between 1950 and 1980, 31.3 trillion gallons of groundwater were withdrawn for irrigation in the central High Plains. Withdrawals from storage were 57%, recycled irrigation water 39% and groundwater diversions/recharge 4%. The 1970 floods provided little recharge here.

Between 1960 and 1980, 34.2 trillion gallons of groundwater were withdrawn for irrigation in the northern High Plains. About 14% was withdrawn from storage, 36% by recycled irrigation water, and 50% from diversions/recharge.

Several factors contribute to the differences between the northern High Plains and the other High Plains areas. In the northern High Plains, more surface-water irrigation occurs. Groundwater recharge rates before irrigation development began were also higher in this area. Land use changes have also had an effect. As more land was brought under cultivation, increased infiltration of rainfall led to more recharge. Because rainfall is more prevalent in the northern High Plains, more recharge occurs. Finally, irrigation in the northern High Plains requires a much lower rate of pumping per square mile than in the southern High Plains.

In the southern and central High Plains, withdrawals from storage have been so great that the aquifer has been dewatered by more than 50% in over 3,500 square miles. This decline affected irrigation in two ways. First, increased energy costs are required because water is pumped from a greater depth. Second, as the saturated thickness of the strata declined, yields of individual wells also declined, so additional wells must be drilled to provide the same water volume. These economic impacts led to the beginning of a gradual decline in the use of groundwater in the High Plains—withdrawals in the southern High Plains declined 11% since 1964. Growers are taking other approaches such as installing more efficient irrigation hardware and shifting to crops and varieties that require less water.

Central Valley of California

The Central Valley of California is the most heavily pumped contiguous area in the United States. The watershed encompasses 20,000 square miles. Prior to development, total groundwater circulation through the aquifer system was 650 billion gallons per year. From 1961 to 1978, about 7.2 trillion gallons per year were used for irrigation in the Central Valley—about half from ground-

water. During this period, groundwater recharge was about 90% of withdrawals; however, 82% of the recharge water came from irrigation water percolating back to the aquifers. Consequently, 261 billion gallons per year were withdrawn from groundwater storage. About half this amount lowered the water table and about half came from dewatering sediments that compacted and led to surface subsidence.

Since 1978, generally wet conditions in the Central Valley stimulated recharge to the point where groundwater withdrawals from storage ceased and some additions to storage occurred. Given the wet weather and current equilibrium in groundwater withdrawals and recharge, Central Valley water managers believe that subsidence can be controlled. The key appears to be limiting withdrawals to keep the water level above its historical low point in subsidence-prone areas.

Southeastern and Atlantic Coastal Plain

Two regional aquifers provide water over a wide area along the Atlantic Coast. One underlies Florida, southern and eastern Georgia, and adjacent areas of South Carolina and Alabama. The second underlies the Atlantic Coast between South Carolina and Long Island. Both have been extensively developed for agricultural, industrial, and municipal supplies. The former aquifer exists primarily in limestone and dolomite rock formations; the latter in unconsolidated sands and gravels of the coastal plain. In both, recharge is excellent due to humid climate and plentiful precipitation.

Extensive development in both aquifers led to declines in water levels. In both aquifers, the effective lower boundary is the transition from circulating freshwater to underlying saline water which moves much slower, if at all. Transition layer location is deepest where recharge is greatest and rises toward the coastlines in the general direction of streamflow. In some parts of coastal Florida, especially the area south of Lake Okeechobee, brackish or saline water extends to the top of the aquifer. Here, and also along the Atlantic Coast, development of the groundwater resource is encouraging saltwater intrusion.

In addition to saltwater intrusion, heavy pumping in these coastal plain aquifers results in a reduction in instream flows. Both the limestone formations beneath the Southeastern Coastal Plain and the unconsolidated sands and gravels beneath the Atlantic Coastal Plain have many intersections with streambeds. Part of the reason that recharge is excellent for these aquifers is due to the ease with which streamflow can be diverted into the rock, sands, and gravels. Because heavy pumping induces a recharge response from all directions, intensive development of these coastal aquifers draws saline water from the oceans and drains freshwater from streams. In some aquifers, such as the Castle Hayne in eastern North Carolina and Virginia, heavy withdrawals for municipal and industrial uses created several large zones of depression that are merging regionally.[6] The long-term consequences of both situations are unfavorable.

Arizona Lowlands

The semiarid lowlands of Arizona cover 50,000 square miles and are the most heavily pumped region in the state. Irrigation is the largest use of water with two-thirds drawn from groundwater. In recent years, competition has been growing between irrigators and municipalities. Tucson is entirely dependent upon groundwater and more than half of Phoenix's supply comes from groundwater.

Vast quantities of groundwater are stored in sediments beneath the basin. Because potential evapotranspiration greatly exceeds precipitation, only limited amounts of water are available for natural recharge to the groundwater. Thus, extensive withdrawals of groundwater from storage resulted. In 1981, about 1.7 trillion gallons of groundwater were pumped, of which 1.4 trillion gallons were used for irrigation. The current annual depletion of groundwater in the area is estimated at 650 billion gallons, or roughly 40% of withdrawals.

A number of hydrologic changes resulted from intensive withdrawals of this magnitude. Groundwater levels declined as much as 400 feet in some places since the 1940s and rates of water-level decline been as great as 8 feet per year. In many areas, water-level declines altered natural flow patterns that existed prior to development, creating a series of small, self-contained individual flow systems near each pumping center. In some areas of extensive water-level decline, the land surface subsided as much as 12 feet and earth fissures caused damage to public and private property. Concerns over land subsidence together with the self-limiting factors inherent in groundwater storage depletion—declining well yields and rising energy costs for pumping—are acting to reduce withdrawal rates.

Groundwater Summary

Patterns of water development in the nation have varied between two general conditions. In water deficient areas, such as southern Arizona and the southern High Plains, long-term withdrawal of groundwater from storage (groundwater mining) has supplied agricultural and municipal needs for many decades. These withdrawals cannot be sustained indefinitely. Decreases in withdrawals are taking place as falling water levels cause well yields to decrease and pumping costs to rise. In humid areas such as the Southeastern and Atlantic Coastal Plains, groundwater development has redistributed the natural flow pattern so that water which originally discharged to streams, to the sea, or to evapotranspiration, is now diverted to well fields. In these areas, the groundwater system conveys water from source areas to points of use and provides short-term storage during drought. The net depletion of groundwater in storage has been small since the aquifers were first developed. In the Central Valley of California, groundwater development has followed a course somewhat between these two conditions. Substantial withdrawals occurred, but the system now appears to be in equilibrium between with-

drawals and recharge. Coordinating the use of both surface and groundwater withdrawals, in which short-term depletions of groundwater are used to make up deficiencies in surface supplies during droughts, and recharging aquifers when surface supplies become more plentiful, should be possible on a sustained basis.

INSTREAM USE

Instream uses include fish and wildlife propagation, recreational activities, maintenance of estuary salinity balances, hydropower generation, navigation, and waste dilution and transportation. In the past, waste dilution and transport was considered the primary use of instream flows. Findings by Wollman and Bonem (1971) ignored water flows needed for navigation and fish habitat, assuming that if sufficient water was available for waste dilution, those needs would also be met. They calculated flows needed for waste dilution at different wastewater treatment rates. They concluded that if municipalities removed 70% of the waste delivered to them and private treatment facilities (generally industrial plants) removed 50% of the waste delivered, then instream flows needed to preserve instream water quality would vary from 1,423 bgd in 1985 to 5,569 bgd in 2020. If 90% of the waste was removed by both public and private facilities, the instream flow needs would be reduced to 231 and 740 bgd in 1985 and 2020 respectively. The maximum volume of instream flows reported by Wollman and Bonem was 956 bgd. Thus, it was clear that with the assumption of 70% and 50% treatment levels, instream water quality would seriously deteriorate.

These findings served as a major impetus for passage of Public Law 92–500, the Federal Water Pollution Control Act Amendments of 1972, also known as the Clean Water Act. This law revised national policy toward instream water quality and wastewater treatment by limiting use of instream flows for additional waste dilution and setting goals for attaining "fishable-swimmable" water quality in most streams through use of "best practicable" and "best attainable" wastewater treatment technologies.

Instream flows for hydropower electricity generation are typically provided by dams. Instream flows typically do not have the required "head" to generate power without some sort of storage and/or diversion structure. These uses will be reviewed below in the surface water development section.

Freshwater stream flows are essential to keep the proper salinity balance in estuaries. Estuaries are often very fertile interfaces between saline ocean waters and freshwater from streams. The resulting brackish waters support extensive commercial and sport fisheries. For example, along the Gulf Coast, brackish water serves as vital breeding habitat for brown and white shrimp, blue crabs, redfish, and speckled trout. Black bass will come down freshwater streams to feed on grass shrimp produced in the brackish water. Thus, maintaining the proper salinity balance with instream freshwater flows becomes critical to sustaining fisheries. Too much freshwater during floods or too little freshwater during droughts are both equally harmful to fisheries depending on brackish water.

Instream flows are also essential for maintaining wetlands and swamps. These ecosystems are also the source of wildlife and fish habitat.

Navigation and recreation activities, such as water skiing and swimming, generally do not suffer benefit losses over a long-term if low instream flows occur. Wildlife and fish populations, on the other hand, do suffer long-term effects from low flows—effects from which they may take years to recover. Recreational and commercial activities associated with wildlife and fish will also suffer long-term losses in benefits if low flows destroy habitat or breeding populations. This Assessment defines necessary instream flow levels based upon wildlife and fish needs.

Generalized Water Budgets

Generalized water budgets have been used by resource planners and managers to evaluate water resource allocations (USGS 1984, Foxworthy and Moody 1986, and Flickinger 1987). Updated water budgets for water resource regions were developed for this Assessment and reflect the latest information (water use data for 1985 from USGS). The first portion of the water budget is presented here, with the final part in Chapter 4, where water supply projections are developed. The objective of the first portion of the budget is to account for groundwater depletion rates and instream flows necessary for optimum wildlife and fish habitat. The balance of instream flows are then available for additional consumption by offstream uses.

Average annual stream outflows at the downstream end of major water resource regions were estimated by Graczyk et al. (1986) (table 2). Average annual stream outflows come from gauging stations and reflect current consumptive use and net reservoir evaporation levels in the basins. For this table, outflows, consumptive use and evaporation are regarded as fixed. When the annual depletion of groundwater storage (from Foxworthy and Moody 1986) is deducted under the assumption it will cease, the balance is the average annual net streamflow available for instream and additional offstream withdrawal uses. Net reservoir evaporation was estimated by Foxworthy and Moody (1986). The instream flows necessary for optimal fish and wildlife habitat were defined by Flickinger (1987). The amount of water available for additional offstream uses is the net amount remaining after instream flow requirements are deducted from average annual net streamflow. Put another way, the remainder is the limit on volume of surface water available for growth in consumption in each water resource region. The analysis shows that instream flows in the Rio Grande, Upper Colorado, and Lower Colorado water resource regions are insufficient to meet current needs for wildlife and fish habitat, much less allow any additional offstream use.

Table 2.—Average annual net streamflow (billion gallons per day), by water resource region, 1985

Water resource region	Area (1000 sq. miles)	Average annual stream outflows[1]	Annual depletion of ground-water storage	Average annual net streamflow	Instream flow requirement[2]	Net flow available for additional offstream uses
New England	69	76.4	0.0	76.4	69.0	7.4
Mid-Atlantic	103	93.8	0.0	93.8	68.8	25.0
South Atlantic-Gulf	271	207.2	0.0	207.2	188.7	18.5
Great Lakes	134	73.0	0.0	73.0	64.0	9.0
Ohio[3]	160	137.4	0.0	137.4	122.0	15.4
Tennessee	43	42.9	0.0	42.9	38.5	4.4
Upper Mississippi[4]	181	79.5	0.0	79.5	69.7	9.8
Lower Mississippi[5]	106	382.9	5.8	377.1	359.0	18.1
Souris-Red-Rainy	55	7.2	0.0	7.2	3.7	3.5
Missouri	511	55.8	2.2	53.6	34.0	19.5
Arkansas-White-Red	244	61.5	3.6	57.9	46.2	11.7
Texas-Gulf	178	34.2	3.1	31.1	22.9	8.2
Rio Grande	137	2.1	0.0	2.1	2.3	-0.2[6]
Upper Colorado	103	7.6	0.0	7.6	8.0	-0.4[6]
Lower Colorado	155	1.4	2.1	-0.7	6.9	-7.6[6]
Great Basin	139	4.5	0.0	4.5	3.4	1.1
Pacific Northwest	271	277.6	0.0	277.6	214.0	63.6
California	165	71.8	1.4	70.4	32.6	37.8
Alaska[7]	586	921.0	0.0	921.0	---	---
Hawaii[7]	6	13.6	0.0	13.6	---	---
Caribbean[7]	4	4.8	0.0	4.8	---	---

[1]*Gauging station outflows, which include current consumptive use, imports/exports, and net reservoir evaporation.*
[2]*Instream flow requirements were taken from Flickinger (1987). They represent the optimal flows for fish and wildlife habitat—the most critical of instream uses—in average flow years.*
[3]*Excluding outflows from the Tennessee region.*
[4]*Excluding outflows from the Missouri region.*
[5]*Land area for the Lower Mississippi region alone. Flows include inflows from the entire Mississippi River basin, including the Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions.*
[6]*Negative numbers indicate that insufficient water currently exists to maintain optimal instream flow conditions and also avoid groundwater depletions.*
[7]*No information on instream flow requirements was available for Alaska, Hawaii, and the Caribbean in Flickinger (1987).*

There are two implications of this current resource situation. The first is that groundwater withdrawals are essential in these regions to maintain current levels of consumptive use. The second is that if growth in offstream uses exceeds the net amount shown or that occurs in the Rio Grande, or Upper or Lower Colorado regions, then either groundwater mining is occurring in excess of current depletion estimates or fish and wildlife habitat is sub-optimal and other instream uses may be curtailed at certain times of the year. In addition to providing habitat, instream flows are essential for maintaining wetlands and swamp ecosystems and for maintaining salinity balances in brackish water ecosystems.

SURFACE WATER DEVELOPMENT[7]

The nation's total endowment of surface water is more than adequate to meet current demands. The real issue is that water is not always available when and where needed. Besides groundwater depletion, the other major reason for water scarcity in an area is increasing competition for what is essentially a fixed supply. For example, from 1960 to 1985, total withdrawals from surface water increased 55% while population increased 32%. This means that surface withdrawals per capita per day have risen from 937 gallons to 1,086 gallons—an increase of 16%.

Water use is analyzed from two perspectives—withdrawals and consumption. Withdrawals are water withdrawn or diverted from a source for use. Consumption is water no longer available for use because it has been evaporated, transpired, incorporated into products or crops; consumed by humans or livestock; or otherwise removed from the water environment. Water withdrawn from a stream is either consumed or returned to the stream, usually after treatment. Water returned is then available for withdrawal and consumption downstream.

Surface water development issues in a particular reach of stream are often most concerned with withdrawals. But from a regional perspective, consumption is the more important measure of use. It is not unusual for withdrawals in a basin to be a multiple of runoff volume because much of the water withdrawn is returned to streams following waste treatment. But total annual consumption cannot exceed total annual runoff at the foot of the basin unless water is withdrawn from groundwater or surface storage. Consequently, water budgets focus on consumption. Surface water structures such as dams, pipes, and canals focus on withdrawals.

In 1985, total freshwater withdrawals in the United States were 343 bgd—83 billion from groundwater, 260 billion from surface water, and 0.6 billion from wastewater. Consumption in 1985 totaled 94 bgd—27% of

withdrawals. Irrigation is the use that has the highest ratio of consumption to withdrawals—51% (73.8 bgd consumed of 142.5 bgd withdrawn). Thermoelectric steam cooling has the lowest consumption ratio, 3% (4.8 bgd consumed of 130.9 bgd withdrawn). These are the two uses with the largest withdrawals. Domestic self-supplied and livestock watering have consumption ratios approaching the ratio of irrigation (47% and 45% respectively), but their combined withdrawals in 1985 only totaled 8.3 bgd. Municipal and industrial self-supplied uses fall in the middle, with consumption ratios of 16% and 22% respectively, and withdrawals of 36.7 and 24.5 bgd respectively. Further information on withdrawal and consumption trends is presented in Chapter 3.

The annual consumption rate of 93 bgd is directly comparable with the "net flow available for offstream uses" column in table 2. Because irrigation consumes 10 times the water of any other use and more than 3 times the total consumed by all other uses, obtaining more water for irrigation was the prime water development problem in the U.S. earlier this century. In recent years, however, increasing population and development of diversified commercial and industrial economies in water resource regions where irrigation was historically the dominant water use have increased the competition for water. Emergence of competing uses for water, both in the short-term during droughts and in the long-term to stimulate development, has heightened concern over the adequacy of water supplies and likelihood of water scarcities that hinder growth of both agricultural and non-agricultural economies.

Four approaches have been used to resolve problems of surface water availability: (1) developing structures to store water when it is plentiful and convey it to the area where and when needed; (2) reducing or preventing certain water losses or uses deemed not beneficial; (3) attempts to increase the amount of precipitation; and (4) changing the nature and efficiency of water uses and treatment processes so water of lower quality can be used. Only the second approach deals with altering demand, the other three all seek to modify timing or amount of the available supply.

Structural Surface Water Developments

Of the four approaches available for dealing with surface water scarcity, society invested the most in building storage and conveyance structures. Unregulated flow of many of the Nation's rivers is highly variable throughout the year. For example, the rate of flow during floods is many times greater than during droughts. Some streams are called "intermittent" because they cease flowing during parts of the year. Most withdrawals, on the other hand, show much less variability—many being nearly constant on a weekly basis. When the rate of withdrawals approaches the average daily flow rate of a river, there are many days during the year when the desired amount of water is unavailable. Thus, reliance upon surface water as a source of supply usually requires damming to create a reservoir to store water from wet periods for use during dry periods. If the reservoir is located upstream from where water is used, water stored behind the dam may be released during dry periods to flow downstream to the point of use. In some cases, stored water is withdrawn directly from the reservoir and carried by pipe or canals to the point of use. In either situation, there are usually minimum instream flows that must be maintained below the dam or the point of diversion.

There are 2,654 reservoirs and controlled natural lakes with capacities of 5,000 acre-feet or more in the United States and Puerto Rico. These have a combined normal storage capacity of 480 million acre-feet. The 574 largest reservoirs account for almost 90% of total storage. In addition, there are at least 50,000 smaller reservoirs with capacities in the range of 50 to 5,000 acre-feet and about 2 million smaller farm ponds used for storage, table 3 (U.S. Army Corps of Engineers, 1981). Distribution of reservoir capacity in the water resource regions of the Nation, expressed as the sum of the normal capacities of all reservoirs larger than 5,000 acre-feet, is shown in table 4 (U.S. Army Corps of Engineers 1981). Normal capacity—the capacity exceeded only during floods—represents a desired storage level for the reservoir and averages about two-thirds of maximum capacity.

Reservoirs are often described as having a "safe yield" which is the amount of water that can be withdrawn or released on an ongoing basis with an acceptable risk of a supply interruption. If the desired safe yield is small in comparison to the average flow rate of the river (say 10% of average flow), then the dry period for which the reservoir stores water may be a few weeks or months of the year's driest part. For a safe yield approaching the average annual river flow (between 50% and 90% of average flow), the dry period for which the reservoir stores water may span several years. The required size of a reservoir to satisfy a given demand is determined by the volume of water necessary to carry users through

Table 3.—Summary of reservoir storage capacity, including controlled natural lakes, in the United States and Puerto Rico, 1981

Reservoir size[1] (acre-feet)	Number of reservoirs	Total reservoir storage: Capacity (1,000 acre-feet)	Percent of total
Greater than 10,000,000	5	107,655	22.4
100,000 to 10,000,000	569	322,852	67.3
50,000 to 100,000	295	20,557	4.3
25,000 to 50,000	374	13,092	2.7
5,000 to 25,000	1,411	5,632	3.3
Total[2]	2,654	479,788	100.0

[1]*Reservoir size is expressed as normal capacity of storage, which is the total storage space in a reservoir below the normal water retention level. Normal capacity includes dead storage and inactive storage but excludes any flood-control or surcharge storage.*

[2]*In addition, there are perhaps at least 50,000 reservoirs with capacities ranging from 50 to 5,000 acre-feet, and about 2 million smaller farm ponds used for storage.*

Source: U.S. Army Corps of Engineers (1981), cited in Anon. (1984)

Table 4.—Distribution of reservoir storage by water resource region, 1981

Water resource region	Area in region 1000 mi²	Average renewable supply, bgd	Normal reservoir capacity Million acre-ft	Acre-ft per square mile	Percentage of renew. supply
New England	69	77.3	13.0	188	15.0
Mid-Atlantic	103	96.5	10.3	100	9.5
South Atlantic-Gulf	271	213.0	38.7	143	16.0
Great Lakes	134	76.8	6.9	51	7.9
Ohio[1]	160	140.0	19.6	123	12.0
Tennessee	43	43.3	11.2	260	23.0
Upper Mississippi[2]	181	79.7	12.2	67	14.0
Lower Mississippi[3]	160	76.0	5.7	36	6.7
Souris-Red-Rainy	55	7.7	8.0	145	93.0
Missouri	511	67.3	84.3	165	112.0
Arkansas-White-Red	244	63.7	31.8	130	45.0
Texas-Gulf	178	35.9	24.7	139	61.0
Rio Grande	137	5.0	10.4	76	189.0
Upper Colorado	103	12.3	37.7	366	261.0
Lower Colorado[4]	155	−1.1[5]	32.7	211	299.0
Great Basin	139	8.3	3.3	24	35.0
Pacific Northwest	271	291.0	60.9	225	19.0
California	165	86.9	38.8	235	42.0
Alaska	586	921.0	1.5	3	0.1
Hawaii	6	14.3	0.0	2	0.0
Caribbean	4	5.1	0.3	90	5.2

[1]*Exclusive of outflows from the Tennessee water resource region*
[2]*Exclusive of outflows from the Missouri water resource region*
[3]*Exclusive of outflows from the Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red water resource regions.*
[4]*Represents conditions in the Upper and Lower Colorado water resource regions.*
[5]*The annual renewable supply of the combined Upper and Lower Colorado water resource regions is 11.2 bgd. The supply for the Upper Colorado was reported as 12.3; the estimate for the Lower Colorado was computed.*

U.S. Army Corps of Engineers (1981), cited in Anon. (1984)

the dry period. This volume is the product of flow deficiency (demand minus flow) and duration of the dry period.

As is the case with pumping groundwater, the law of diminishing returns applies. Each successive increment in safe yield requires more storage than the preceding increment. For example, doubling safe yield would require more than doubling storage capacity, which, in turn, requires more than doubling construction costs. Hardison (1972) found that, for all water resource regions in the continental U.S., the point at which safe yield reaches its maximum is when storage is in the range of 160 to 460% of average renewable supply of the region. The variation depends, in part, upon the use or variety of uses (such as water supply, flood control, power generation) served by the stored water.

Another index of reservoir capacity is normal reservoir capacity in the region per unit area of the region. If Alaska and Hawaii are excluded, the range in intensity of development among regions is considerable—ranging from 24 acre-feet per square mile in the Great Basin to 366 acre-feet per square mile in the Upper Colorado. Factors influencing the intensity of development include availability of precipitation and groundwater to help satisfy water demands, magnitude of the surface flows available for development, existence of suitable reservoir sites, and political and institutional factors governing reservoir development. The upper limits on development of suitable sites among regions appear to range from about 250 to about 500 acre-feet per square mile (Langbein 1982).

Historical trends in reservoir development show an average growth rate in capacity of major reservoirs in the United States of about 80% per decade from 1920 to the early 1960s. Since then, reservoir capacity increased at a much slower rate. The current status of reservoir development is about 450 million acre-feet. Based on a number of intensive surveys, there remain about 750 million acre-feet of potential storage in the continental U.S. where building dams is feasible from an engineering perspective. Because most cost-effective sites have been developed, adding a significant portion of the potential storage to the current level of development will entail very high investments—so high as to be nearly prohibitive. If so, the Nation's current reservoir capacity may be near the limit of development.

There are, however, other means for coping with providing water to meet future demands. Most of these are non-structural measures that require changing management guidelines or regulations. Such changes, of course, often have costs of their own—social and environmental as well as economic. For example, there are a large number of multiple-purpose reservoirs where withdrawals are not now the primary purpose of management. A shift in water allocation could make additional capacity available to meet future water supply shortages in time

of drought. Better management has the potential for increasing safe yields, up to a limit, without increasing storage (Toebes 1981).

An example of better reservoir management is found in the Washington, DC metropolitan area (Sheer 1983). The area's water supply comes from three rivers and four reservoirs: the Potomac, with one reservoir 200 miles upstream; the Patuxent in Maryland, with Tridelphia and Rocky Gorge Reservoirs; and the Occoquan, with Occoquan Reservoir. The sum of safe yields of these three sources is 513 million gallons per day, but demand for water is expected to reach 750 million gallons per day by the year 2000. Through analyses of the complete system—intentionally ignoring certain institutional constraints of three separate water supply agencies—it was found that existing structures could reliably supply water until the year 2030. After recognizing the large gains that could be achieved through flexible and integrated operations, those involved forged the necessary legal and financial agreements to make this possible. The savings are in excess of $200 million. These savings were achieved through systems analysis techniques such as linear programming, synthetic hydrology, statistical analysis, hydrologic modeling, long-range probabilistic forecasting, and computer simulation.

The trend towards using nonstructural measures to solve problems instead of building more dams places greater dependence upon management skill, understanding the nature of river behavior, and better river forecasting. At some point, potentials for conservation and better management may become less cost effective than building additional storage.

Controlling Losses and Low-Priority Uses

A number of options are available for eliminating or curtailing water losses and uses judged not beneficial, given current supplies. One is to reduce water leaks from pipes and ditches delivering water to municipal and irrigation users. Stopping leaks does not make more water available in a region because leakage returns to aquifers. But it is a way of increasing the usable supply at low cost because leakage water has been diverted, treated and transported—often at high cost—yet is never available for use. Moyer et al. (1983) and Pilzer (1981) analyzed leak detection programs.

Implementing voluntary or mandatory rationing schemes is the quickest way to curtail low priority water uses. Mandatory actions such as restricting lawn watering to one day in three or prohibiting automobile washing during a drought period were employed during recent droughts in the East. Some citizens adapted to such restrictions by using rinse water from laundry to water vegetable gardens or wash vehicles—a form of household recycling. Other forms of voluntary household conservation include installing a showerhead that emits fewer gallons per minute and bending the float arm in toilet tanks to reduce the volume of water per flush.

Voluntary or mandatory rationing schemes are but one type of institutional modification that can reduce demand and stretch available supplies. Experience with such institutional changes demonstrates that there are few absolute water requirements. Most offstream water users have considerable flexibility in selecting rates of water intake and recycling. Water use may change, for example, in response to changes in water prices or waste treatment charges (Foster and Beattie, 1979; Strudler and Strand, 1983; and Young et al., 1983). Installation of water meters has led to reductions in water use in some areas; a contributing factor is often the switch from flat rate to variable rate structures. Industrial users may change water use practices in response to energy prices and waste treatment regulations (Babin et al., 1980). Irrigators are moving to more efficient irrigation hardware and management methods. The Federal Interagency Task Force on Irrigation Efficiencies (1979) estimated that $5 billion in public and private expenditures on water conservation by 2010 could reduce withdrawals by 13 to 18 bgd and thereby make 1.7 to 4.5 billion gallons available for new consumptive uses. In some western states, the appropriation doctrine of water rights limits user flexibility to sell water not currently needed, often placing users in a "use it or lose it" situation. Modifications in the water-rights institution can help shift water from users who have more senior rights to those with junior rights. Ideally, such changes could be temporary so the owner of senior rights does not lose them permanently or through markets enabling junior users to bid for rights.

A detailed discussion of the many forces influencing water use and of various demand management practices and policies is beyond the scope of this Assessment. Kelso et al. (1973) examined some of these problems in a case study of Arizona. Hirshleifer et al. (1969) and Baumol and Oates (1979) provide a more general discussion of these topics.

Increasing Precipitation

Weather modification is another approach to enhancing water supplies. Serious scientific attention to techniques for artificially increasing precipitation began around 1946. There have been more than a dozen major research projects dealing with this subject in the United States. Findings of these studies are the subject of controversy in scientific literature. See, for example, Hess (1974), Tukey et al. (1978) and Braham (1979).

Ski areas in California and Colorado are practicing weather modification on a commercial basis. However, serious impacts on stream channels can occur where snow accumulates in excess of what stream channels can handle during snowmelt. Reservoir capacity must be available to store increased snowmelt if this runoff is to contribute to increased regional water supplies.

Using Low Quality Water

Using water of lower quality, such as recycling treated wastewater, has not become as popular as some forecast

when Congress debated the Federal Water Pollution Control Act Amendments of 1972. Wastewater use today is 5% lower than in 1960. Between then and now, use peaked 10% higher than present and dropped 20% below present. A decided trend in wastewater use is not evident, except it has not increased nearly as much as expected. Wastewater reuse is not new. Bethlehem Steel in Baltimore, MD has used over 100 million gallons per day of Baltimore's treated wastewater since 1942.

Saline water use has increased seven-fold from 1950 to 1980 (Solley et al., 1983), mostly for industrial cooling purposes. Saline water use represents an enhancement of supply, but presents problems for industry. The rate of increase in saline use, however, demonstrates that solving those problems has proven less costly than acquiring additional supplies of freshwater.

QUALITY OF WATER AVAILABLE FOR USE[8]

Water-quality degradation is widely publicized but has not become a major limitation on water availability or use nationwide. A relative abundance of good quality surface water still exists, even though serious water-quality problems have developed in some stream reaches and some streams cannot support the full range of desired uses.

There are six major categories of pollutants:

1. Disease-causing organisms—Fecal coliform bacteria are used as indicators of the presence of other infectious agents including bacteria, fungi, and viruses.
2. Nutrients—These stimulate aquatic plant growth, and can result in altered aquatic communities, fish kills, excess weed growth, unpleasant odors and tastes, and impaired recreational uses.
3. Silts and suspended solids—These modify aquatic communities through habitat alteration, impair fish respiration and reproduction, and reduce plant productivity by reducing sunlight penetration and photosynthesis. Silts and solids, known as turbidity, may reduce aesthetic appeal and recreational uses.
4. Biochemical oxygen demand (BOD)—These materials reduce availability of dissolved oxygen crucial to respiration of fish and aquatic invertebrates.
5. Salinity and total dissolved solids—These materials impair the use of water for drinking and crop irrigation and adversely affect aquatic ecosystems.
6. Toxics—These substances can cause death, mutation, or reproductive failure in fish and wildlife and may pose carcinogenic or other health threats to humans.

Water pollution is usually attributed to one of two sources—point or nonpoint—depending upon how water enters the aquatic environment. Point sources discharge a flow to the aquatic environment through a pipe, ditch, or other mode of conveyance. Nonpoint sources discharge a flow to the aquatic environment as runoff, not collected or concentrated by a conveyance structure.

During the 1960s, growing environmental awareness of water quality issues led to passage of several laws pertaining to water quality. The Clean Water Act of 1972 (amended in 1977 and 1981) and the Safe Drinking Water Act of 1974 (Public Law 93–523) were two of the most prominent. These laws motivated both the public and private sectors to spend billions on different types of pollution abatement programs, designed mainly to reduce point-source pollution and improve instream quality. For example, more than $100 billion was spent for pollution control between 1974 and 1981 (U.S. Environmental Protection Agency 1984). From 1972 to 1982, total biochemical oxygen demand (BOD) load from municipal waste treatment plants decreased an estimated 46% and industrial load decreased at least 71% (ASIWPCA 1984). These gains in waste treatment occurred simultaneously with increases in population and real Gross National Product (GNP) of 10% and 27% respectively.

Significant improvements have been reported by the National Stream Quality Accounting Network (NASQUAN) stations operated by USGS and the National Stream Quality Surveillance System (NWQSS) operated by EPA. Between October 1974 and October 1984, widespread decreases in fecal coliform bacteria, lead concentrations, and phosphorus concentrations have been monitored downstream of major point-source dischargers (Smith et al., 1986 and 1987). These trends provide some evidence of benefits of improved wastewater treatment for point-source discharges and benefits from the switch to unleaded gasoline. The same studies, however, have also shown widespread increases in nitrate, chloride, arsenic, and cadmium concentrations. Recorded increases in nitrogen fertilizer applications and use of salt on highways along with regionally variable trends in coal production and combustion are reflected in increasing nonpoint-source pollution loads.

Every two years, EPA summarizes water-quality reports submitted by the States and other jurisdictions in accordance with Section 305(b) of the Clean Water Act, as amended. The 1986 Report (EPA, 1987) marked the first time that all states and jurisdictions submitted data.[9] These data show that three-fourths of the Nation's rivers, lakes, and streams are fully supporting their designated uses (table 5).

States were asked to rank pollution sources impairing the ability of surface and groundwater to fulfill desired uses. Nonpoint sources are responsible for impairing water quality much more frequently than point-source pollution. Of assessed waters with impaired uses, nonpoint sources of pollution were responsible in 76% of lake acres, 65% of stream miles, and 45% of estuarine square miles. Point sources were responsible in 34% of estuarine square miles, 27% of stream miles, and 9% of lake acres.

In 1986 reports under Section 305(b) of the Clean Water Act, States were asked to provide individual discussions of issues found to be of either current or emerging special concern (EPA 1987). Surface water concerns most often discussed by States included mine drainage, nonpoint-source pollution, toxics and public health, acid deposition, groundwater protection, and wetlands loss.[10]

Table 5.—Degree of designated use supported by the Nation's waters, 1986

	Rivers (miles)	Lakes (acres)	Estuaries[1] (sq. miles)
Total in U.S.	1,800,000	39,400,000	32,000
Total Assessed	370,544	12,531,846	17,606
(% of total in U.S.)	(21%)	(32%)	(55%)
Fully supporting uses	274,537	9,202,752	13,154
(% of total assessed)	(74%)	(73%)	(75%)
Uses are impaired			
Partially supporting uses	70,196	2,181,331	3,224
(% of total assessed)	(19%)	(17%)	(18%)
Not supporting uses	22,974	859,080	1,177
(% of total assessed)	(6%)	(7%)	(7%)
Unknown support of uses	2,127	288,684	51
(% of total assessed)	(1%)	(2%)	(0.3%)

[1]*Total U.S. estuarine square miles exclude Alaska*

Source: EPA (1987)

In the mid-1970s, experts believed that point-source pollution was the more significant source. Accordingly, efforts to improve water quality were focused upon point sources discharging more than 5 million gallons per day. The effect was to target grant and enforcement programs on roughly a fifth of the dischargers, who in total, created nearly four-fifths of the total volume discharged. Obtaining compliance by this group required substantial public and private investments and water quality has improved. Obtaining similar compliance by the remaining large number of small point-source dischargers will be more difficult and not nearly as cost-effective. Further, as the large point-source discharges were brought into compliance, it became more and more evident that nonpoint sources (which are even more difficult to track and costly to control than small point sources) were also a major cause of water quality problems.

POINT-SOURCE POLLUTION

There are three major types of point-source dischargers—municipal sewage treatment plants, industrial facilities, and combined sewer overflows. Municipal sewage treatment plants commonly discharge BOD, bacteria, nutrients, ammonia, and toxics. Industrial facilities commonly discharge BOD. There are a wide variety of other substances discharged by industries, depending upon their manufacturing processes. Chief concerns center around toxics. Combined sewer overflows occur where urban stormwater runoff flows into catch basins that empty into the same sewer pipes as residential and industrial wasteflows. If the runoff volume exceeds the short-term conveyance capacity of sewers, excess water causes sewers to overflow and dump a mixture of stormwater runoff and untreated residential and industrial waste into nearby surface waters. The most common pollutants in combined sewer overflows are BOD, bacteria, turbidity, total dissolved solids, ammonia, and toxics.

Biochemical Oxygen Demand

In the decade after passage of the Clean Water Act, municipal loads of BOD decreased 46% and industrial BOD loads decreased 71% nationally. Industrial sources currently contribute about one-third of the total point-source BOD load nationwide. Most industrial BOD load reduction occurred in the mid-1970s shortly after the law was passed. Municipal reductions occurred later, in the early 1980s. Federal expenditures for upgrading municipal facilities under the Construction Grants Program reached a maximum in 1980 and totaled $35 billion from 1972 to 1982. Smith et al. (1987) outlined results of statistical analyses of BOD reductions and changes in dissolved oxygen deficits. They reported little statistical support for concluding that construction expenditures reducing BOD loads had a significant effect on reducing dissolved oxygen deficits. This finding is contrary to surveys of state and local pollution control personnel (ASIWPCA 1985) which reported increased instream dissolved oxygen concentrations.

Bacteria

Decreases in fecal coliform and fecal streptococcal bacteria were widespread from 1972 to 1982. Decreases in fecal streptococcal bacteria were especially common in parts of the Gulf Coast, central Mississippi, and the Columbia basins. Decreases in both forms of bacteria were common in the Arkansas-White-Red basin and along the Atlantic Coast. A major emphasis of the Construction Grants Program was installation of secondary treatment as the minimum treatment level. This led to construction of centralized waste collection and treatment facilities for the first time in many communities. Whenever new collection sewers were installed, they were kept separate from stormwater collection sewers. In many cases, new residential and industrial sewers were constructed to segregate residential and industrial wastes from stormwater.

Another major source of fecal bacteria is runoff from animal feedlots, a nonpoint source of bacteria. Several lines of evidence suggest that the widespread decreases in fecal bacteria are due to improved municipal waste treatment and not to any concerted effort to reduce feedlot runoff. Where fecal bacteria increases have been measured in recent years, they are positively associated with cattle population density and feedlot activity in the watershed (Smith et al. 1987).

Mine Drainage

When thinking of industrial facilities, manufacturing plants more often come to mind than resource extrac-

tion facilities. But water pollution from resource extraction operations was recognized as a major problem as far back as the 1800s. Although most resource extraction operations create nonpoint-source pollution, mines create both point- and nonpoint-source pollution.

In spite of tremendous strides that the mining industry has made to clean up abandoned mines and control discharges from active ones, mine drainage was still reported as one of the major point-source concerns by nine States in their 305(b) reports (EPA 1987) (fig. 4). In addition, mining activities were widely reported by states as a cause of use impairment across the Nation.

Mine-related sources cause a variety of impacts to rivers and lakes. Acid mine drainage occurs when sulfur-bearing minerals are exposed to water and air in the mining process and join to form sulfuric acid. Contaminated water draining or seeping from mines can create acidic conditions in receiving streams. This may dissolve metals from geologic formations and carry these into waterways and, when entering a pH-neutral stream, may form iron compounds that "settle out" and smother bottom-dwelling aquatic organisms, thus creating havoc with aquatic ecosystems (EPA 1987). These factors can devastate streams for miles downstream of mining activity. Cleanup and control, always a complex issue, is complicated further because many of the worst problems come from mines operated and abandoned long before water quality impacts were a consideration.

Metal mines, such as silver, lead, and copper, most widely found in the western U.S., can directly contribute metal-laden runoff through tailings piles and mine seepage. Sedimentation, erosion, and habitat destruction resulting from earthmoving activities are also significant problems associated with mining.

Point-source discharges from active mines are regulated by EPA and state National Pollutant Discharge Elimination System permits. Many states also use Best Management Practices (BMPs) to regulate nonpoint emissions from mines. Pollution from abandoned mines is addressed in the Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95–87). Programs to control runoff from abandoned mines include treating wastes; reclaiming land through refilling, regrading, and replanting; and sealing mine openings.

NONPOINT-SOURCE POLLUTION

There are seven major types of nonpoint-source pollution dealing with some form of runoff. Categories and the types of pollutants commonly found include:

1. Agricultural runoff—Nutrients, turbidity, total dissolved solids, toxics, and bacteria;
2. Urban runoff—Same pollutant categories as agricultural runoff, but in different concentrations;
3. Silvicultural runoff—Nutrients, turbidity, toxics;
4. Construction runoff—Same pollutant categories as silvicultural runoff, but in different concentrations;
5. Mining runoff—Turbidity, acids, toxics, total dissolved solids;
6. Landfills/spills—Toxics, miscellaneous substances;
7. Septic systems—Bacteria, nutrients.

Bacteria, nutrients (principally nitrates, ammonia, phosphorus), and turbidity (suspended sediments) are the key nonpoint-source pollutants.

Thomas (1985) suggested that nonpoint-source pollution may prevent achievement of national water-quality goals even after complete implementation of planned point-source controls. Sixteen states identified nonpoint-source pollution as an issue of special concern in their 305(b) reports (fig. 5). Suspended sediment and nutrients

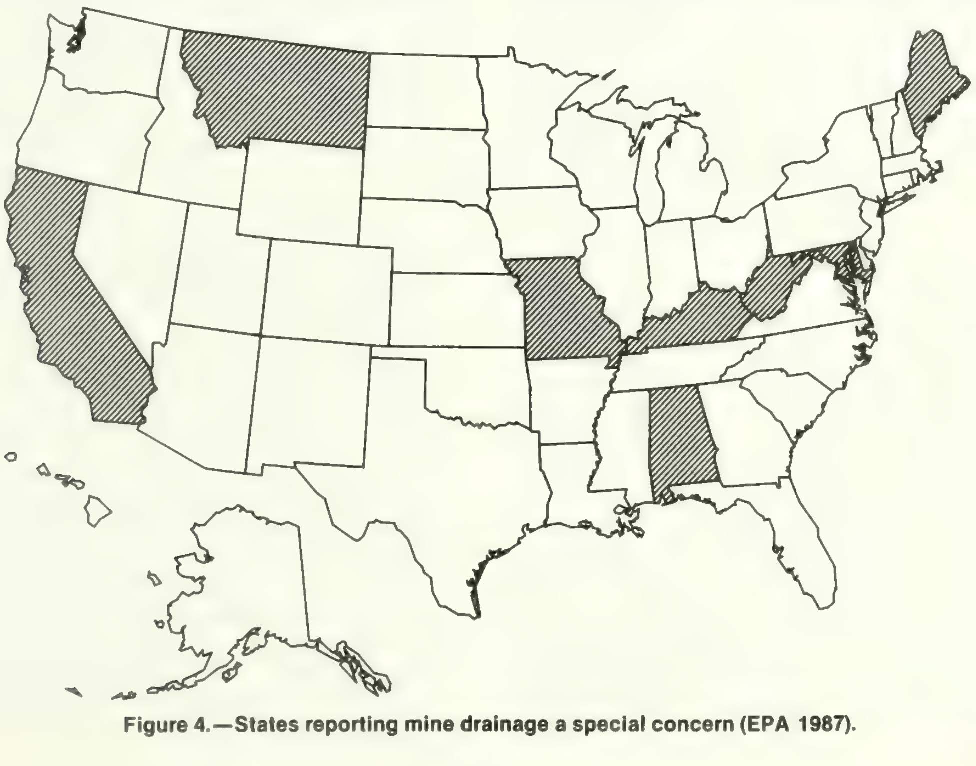


Figure 4.—States reporting mine drainage a special concern (EPA 1987).

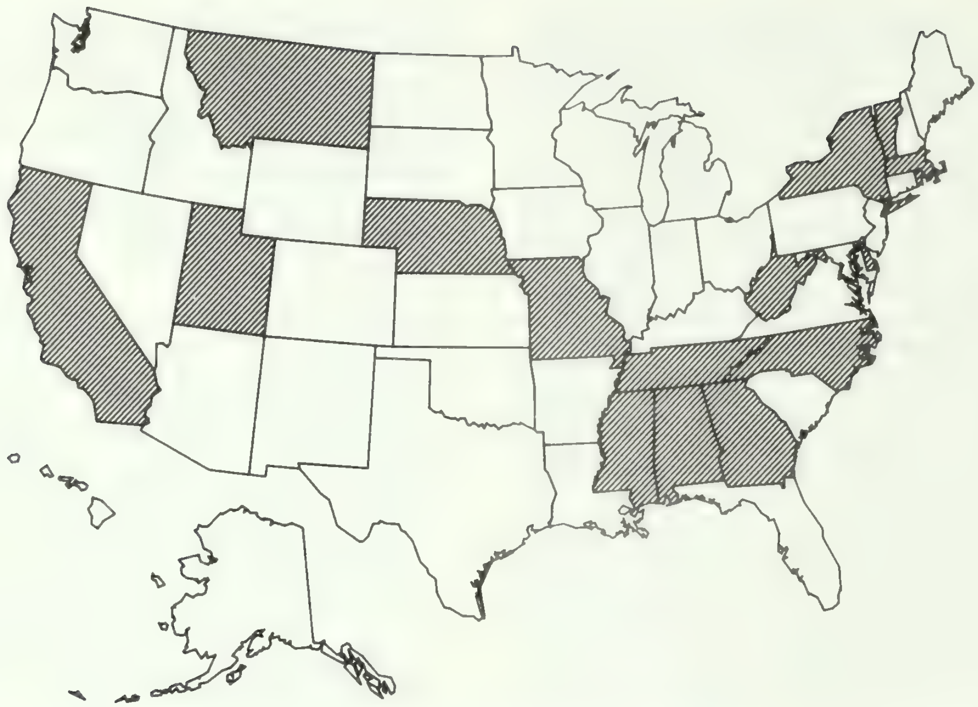


Figure 5.—States reporting nonpoint-source pollution as a special concern (EPA 1987).

from agricultural sources are cited as the most damaging nonpoint-source pollutants nationally. The cost of the hydrologic impacts of soil erosion and related nutrients on aquatic ecosystems has been estimated at $3.5 billion annually (Clark et al. 1985). In spite of wide recognition of nonpoint-source pollution problems, little information is available on long-term trends of nonpoint-source pollution.

Farm activity increased significantly between 1972 and 1982. Fertilizer application rates increased 68% between 1970 and 1981 as farm production increased rapidly (Smith et al. 1987). The extent to which these and other changes in land management practices, primarily agricultural, are reflected in trends in suspended solids, nitrogen, and phosphorus concentrations in streams has largely been a matter of guesswork because no systematic long-term studies are available (Smith et al. 1987).

Suspended Sediment

Nationwide trends from 1974 to 1980 in suspended sediment concentrations were mixed, reflecting both increases and decreases. Increases in suspended sediment concentrations occurred in watersheds where the predominant forms of land use have historically been associated with high rates of soil erosion. An example is logging in the Columbia basin. Smith et al. (1987) tested the association between suspended sediment trends in streams and erosion rates for specific land use categories by using the USDA National Resources Inventory from 1982. They found that trends in suspended sediments were not significantly associated with estimates of total watershed soils erosion. Increases in suspended sediments, however, were significantly related to soil erosion contributed by cropland in the watershed. In contrast to these results, suspended sediment concentrations were *not* associated with erosion rates on forest land, pasture, or range.

Factors other than soil erosion have played an important part in suspended sediment concentrations in streams in some watersheds. For example, some streams in the Columbia basin carried increased sediment loads in 1980 and 1981 after the eruption of Mount St. Helens. Declining concentrations have been reported at several locations in the Missouri River basin and have been clearly traced to the effects of reservoir construction throughout that basin in the 1950s and 1960s (Williams and Wolman 1986).

Phosphorus and Nitrates

Trends in total phosphorus concentrations followed a pattern similar to that of suspended sediments with the exception that decreases in total phosphorus were prevalent in the Great Lakes and Upper Mississippi basins. Decreases in the Great Lakes region resulted partly from point-source reductions in the late 1970s. Increases in the Great Lakes region resulted largely from nonpoint sources. As with sediments, phosphorus increases are significantly associated with various measures of agricultural land use including fertilized acreage and cattle population density. Additional evidence is provided by the close relationship between changes in phosphorus concentrations and changes in suspended sediment concentrations which have already been shown closely linked to agricultural land use changes.

In contrast to suspended sediments and total phosphorus, increasing trends in total nitrate concen-

trations were common and widespread. Increasing trends were most prevalent in the North and South. Increases in total nitrates were strongly associated with several measures of agricultural activity including fertilized acreage as a percentage of watershed areas, livestock population density, and feedlot activity.

In addition to agricultural runoff, atmospheric deposition became a major source of nitrate in surface waters, especially in forested watersheds of the North. Few nitrate deposition records exist for the years before 1980, but those that do (National Academy of Sciences, 1983; Galloway et al., 1982), together with emission estimates for nitrous oxides (Gschwandtner et al., 1985) show a general pattern of increasing rates during the 1974-to-1981 period. Consistent with this trend, total nitrate increases at monitoring stations were strongly associated with high levels of atmospheric nitrate deposition, particularly in the Ohio, Mid-Atlantic, Great Lakes, and Upper Mississippi water resource regions.

Point-source nitrogen loads declined in many watersheds during the late 1970s as a result of improvements in municipal wastewater treatment facilities. But improvements in point-source nitrate loads had no statistically significant effect upon nitrate concentrations instream (Smith et al. 1987). Consequently, total nitrate trends appear more related to nonpoint sources than to point sources. In particular, atmospheric deposition of nitrates may have played a large role in the frequent occurrence of total nitrate increases in midwestern and eastern watersheds.

Given the large increases in fertilizer application rates that occurred in the 1970s and early 1980s, it is not surprising that trends in both total phosphorus and total nitrates show strong associations with measures of agricultural activity. Despite the importance of agricultural sources, however, distinct differences exist in trend patterns for phosphorus and nitrates. Increasing trends in phosphorus and suspended sediment concentrations occurred with only moderate frequency and were largely confined to major mid-continent watersheds. In comparison, increasing trends in nitrate concentrations occurred with high frequency and were widely distributed from the Great Plains eastward. The differences in pollution patterns appear to result from three factors. First, atmospheric deposition seems to have played a large role in the high frequency of increasing trends in nitrate concentrations, especially among forested watersheds in the Lake States, Central States, and East. Second, low frequency increasing trends in, and strong association between, phosphorus and suspended sediment concentrations suggest that anticipated increases in phosphorus concentrations resulting from increases in agricultural activity in the 1970s were moderated or delayed by temporary storage of phosphorus in the soil and sediments in stream channels. Ellis (1973) and Hook et al. (1973) described mechanisms whereby phosphorus applied to forest and agricultural soils in wastewater was either adsorbed by soil colloids and sediments or precipitated from soil solution. Both mechanisms functioned most effectively in the top 6 to 12 inches of the soil. These findings support the moderation or delay findings of Smith et al. (1987). Third, point-source control efforts during the late 1970s and early 1980s focused much more heavily upon phosphorus than nitrates because phosphorus was considered more limiting to eutrophication in freshwater ecosystems. Results of this policy difference are observable both in the greater ratio of phosphorus-decreasing trends to increasing trends and in the stronger association of phosphorus-decreasing trends with point-source load concentrations.

Perhaps the greatest consequence of differences in the nitrogen and phosphorus concentration trend patterns is seen in recent changes in volumes of nutrients delivered to coastal freshwater and marine estuaries. Nitrate loads to Atlantic Coast estuaries, the Great Lakes, and the Gulf of Mexico increased between 25% and 45% between 1974 and 1981 while phosphorus concentrations declined as much as 20%. The exception to this phosphorus finding is the South Atlantic Coast and Gulf Coast where increases in sediment deliveries have also brought increases in phosphorus. There is increasing concern over the problem of eutrophication in estuaries and debate has arisen over the need for nutrient controls in tributary basins (Thomas 1985). Increased deliveries of nitrate to estuaries are a major concern because of the tendency of nitrogen to be the limiting factor for eutrophication in many estuarine environments. For example, emerging problems due to excessive nutrients in the Chesapeake Bay resulted in the Governors of Maryland, Pennsylvania, and Virginia and the Mayor of the District of Columbia creating the Chesapeake Bay Agreement of 1983. Since signing the agreement, interagency networks were developed to deliver educational, technical and financial assistance to dischargers and landowners. Grants to install BMPs for control of nonpoint-source pollution reduced runoff and erosion from 61,120 agricultural acres by 364,000 tons of sediment and provided controls for 830,000 tons of animal waste. EPA (1987) contains additional case studies where reductions in nutrient and sediment deliveries to estuaries, lakes, and streams were recently accomplished.

Total Dissolved Solids (Salinity)

Increasing trends in concentrations of chloride, sulfate, and sodium in streams have occurred since the mid-1970s. The magnitude of the increase—averaging 30%—and the wide distribution of these trends represents a significant increase in salinity in the Nation's waters.

Several factors appear responsible for the general pattern of salinity increases. First, chloride trends were moderately correlated with population changes from 1974 to 1981. Because human wastes are a major source of chloride in many populated basins, increasing trends are not unexpected. Second, salt use on highways increased nationally by a factor of 12 between 1950 and 1980. This trend stands out as a likely cause for sodium and chloride trends in watersheds where a significant portion of annual precipitation falls in the winter

months. Increasing sodium and chloride concentrations were significantly associated with high rates and large increases in highway salt use, especially in the Ohio, Tennessee, lower Missouri, and Arkansas-White-Red water resource regions. Although irrigated agriculture has a large influence on salinity in certain western rivers, chloride trends were not significantly correlated with changes in irrigated acreages nationally (Smith et al. 1987).

Increases in sulfates were especially frequent in the Missouri, Arkansas-White-Red, and Tennessee water resource regions and were highly correlated with changes in open-pit coal production. Sulfate trends were not significantly correlated with underground coal mining in the same water resource regions.

In contrast to most of the nation, the Upper and Lower Colorado water resource regions showed significant decreases in salinity between 1974 and 1981. Decreases in chloride concentrations in these watersheds are noteworthy in view of the history of salt problems there. Decreases were traced to salinity control efforts and temporary effects of reservoir filling in the early 1970s.

Toxics

Although many chemicals have toxic effects if present in sufficient amounts (e.g. table salt) a number of chemicals appear to have adverse and long-term effects at extremely low concentrations. These are commonly referred to as *toxics*. They may be either naturally occurring, such as heavy metals, or synthetic, such as some pesticides. They may be persistent or dissipate quickly. The key is that effects result from very low dosages and often are cumulative so that consequences do not emerge until some time after exposure.

In 1986, 16 states reported that toxic substances or some aspect of toxic substance control is an issue of special concern (fig. 6).

The problem of controlling toxics is particularly troublesome because of the Nation's dependence upon products that may contain hazardous substances or lead to the creation of hazardous substances. Over 60,000 commercial chemical substances are currently in use in the U.S. More than 50,000 pesticide products have been registered since 1947. About 3.5 billion pounds of formulated pesticide products are used each year. Benefits created by using these products in everyday life is substantial, so a wholesale retreat from their use is unlikely. Therefore, the key is to prevent misuse of these products and avoid actions resulting in environmental degradation and health risks. There is also a need to clean up those sites and waters that are contaminated.

Recent advances in monitoring and analytical precision have allowed a much more detailed description of trace elements in surface waters than was available a decade ago. Although no long-term records exist, short-term records frequently show increasing trends in the dissolved forms of two potentially toxic heavy metals—arsenic and cadmium. The dissolved forms are of particular concern because they can enter potable water supplies more readily than suspended materials. Increasing trends in arsenic and cadmium concentrations occurred with greatest frequency in watersheds in the Lake States and northern Great Plains. Evidence suggests that increased atmospheric deposition of fossil-fuel combustion byproducts was the predominant cause of increases in both elements (Smith et al. 1987). Runoff from

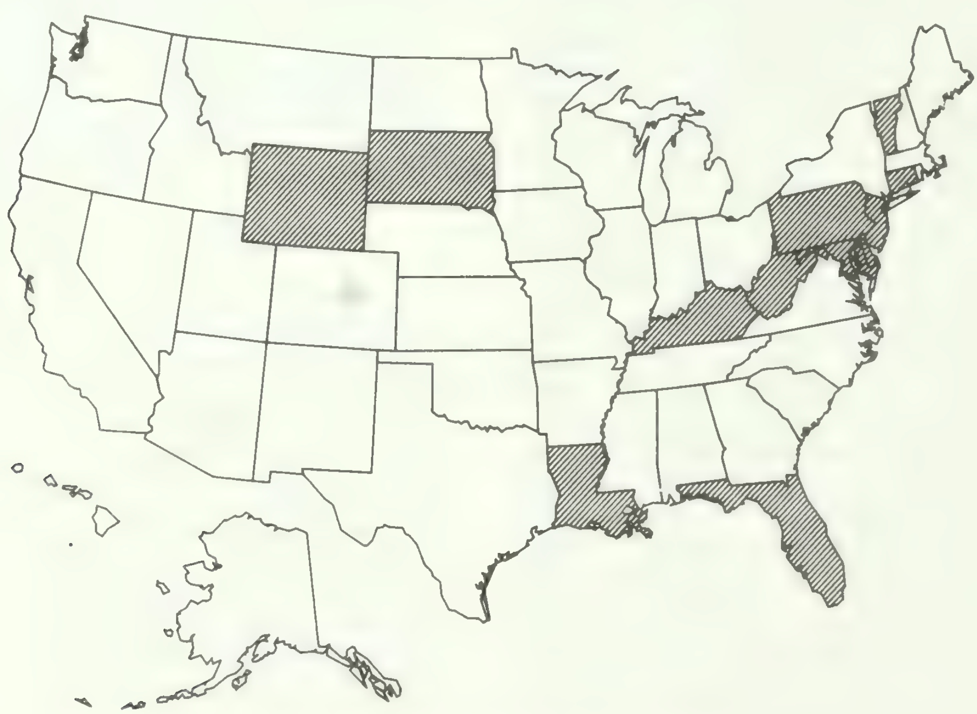


Figure 6.—States reporting control of toxic substances as a special concern (EPA 1987).

fly-ash storage areas near power plants and nonferrous smelters is the other typical way that combustion byproducts enter surface waters. Other sources of arsenic and cadmium entering waste streams include primary metals manufacturing and plating, pesticides, herbicides, and phosphate-bearing commodities such as detergents and fertilizers.

In contrast to arsenic and cadmium, concentrations of dissolved lead have decreased across the Nation. Principal areas of decrease are heavily populated areas of the East and West coasts and along the Missouri and Mississippi Rivers. The decline is due to a shift from leaded to unleaded gasoline. Consumption of leaded gasoline declined 67% between 1975 and 1981. In addition, lead concentrations in leaded gasoline also declined in the same period. Declines in airborne lead have been reported for many U.S. cities. Exceptions to the observed decline of lead in streams and air are the Ohio and Great Lakes water resource regions. Although leaded gasoline consumption declined in these regions, lead concentrations in streams did not. Unknown factors related to the solubility and transport of lead have influenced lead concentrations in streams in these regions.

Urban stormwater runoff is a major source of heavy metals entering surface waters. Concentrations of some heavy metals can be significantly higher in street sweepings than in naturally-occurring soils, rocks, and sediments (table 6). Shale was selected as the rock for comparison because it is a sedimentary rock and represents naturally occurring concentrations in the absence of human influences. All metals in the table are used in common industrial processes or in domestic materials.

Pesticides, including insecticides and herbicides, are applied extensively to crop, pasture, and forest land throughout the Nation. In urban areas they are used on lawns, gardens, and to exterminate pests in buildings and homes. Pesticides in runoff from cropland have been investigated, but little work was done on pesticide residues and other organic substances in urban runoff, although significant concentrations of many of these substances have been measured in urban runoff.

Because of the wide variety of pesticides in use, diversity of application from place to place, and complexity of processes which control amounts of these substances washing from agricultural land, studies attempting to quantify pesticide concentrations in streams from particular land uses or land applications have proven fruitless (Anon. 1984). However, some broad patterns have been recognized in relationships between application methods, chemical properties of certain common pesticides, and losses from the soil (Wauchope 1978).

The greatest release of pesticides has been on farms (Eichers et al. 1978), of which about 98% was applied to crops and 2% to livestock. Corn, cotton, wheat, sorghum, rice, other grains, soybeans, tobacco, peanuts, alfalfa, other hay and forage, and pasture and rangeland accounted for 85% of pesticides used on crops. Nationally, the total volume of insecticides used annually is shrinking; largely because new products are more potent and thus applied at lower rates. For example, since 1976, fenvalerate and permethrin use on cotton at very low application rates largely replaced toxaphene and methyl parathion which were applied at much higher dosage rates to obtain equivalent protection. Less than 100 million pounds of insecticides are currently applied annually to crop, pasture, range, and forest land. Nationally, the total volume of herbicides applied to crop, pasture, range, and forest land increased from 100 million pounds in 1966 to 500 million pounds in 1982. These poundages do not include quantities applied in urban and suburban areas, primarily by homeowners.

Organochlorine insecticides, such as DDT, chlordane, and dieldrin, are strongly adsorbed by soil particles and enter surface waters as a result of soil erosion. Use of these products has been largely banned but, because they are so resistent to decay, they continue to be found in stream sediments. From 1975 to 1980, the Pesticide Monitoring Network (Gilliom 1985) found traces of organochlorine pesticides in more than 50% of streambed sediments sampled, but in less than 5% of water samples. Historically, toxaphene, methoxychlor, DDT, and aldrin were most heavily used; consequently, they should show up in samples most frequently. However, available tests for toxaphene and methoxychlor are the least sensitive of the tests for all organochlorine pesticides so they are seldom found. DDT and aldrin break down rapidly, so are rarely detected. Byproducts of their degradation, however, are found frequently. In contrast to these more heavily used compounds, lindane has been used relatively little, but was the most frequently detected organochlorine in water because of lindane's relatively high solubility, high persistence, and easy detection. Lindane is one of the products recommended for use in control of the southern pine beetle and, given its properties just cited, care is needed to keep lindane out of surface waters. Chlordane was one of the most common termiticides used to treat building foundations. From a quantity standpoint, it was about as popular as lindane. Because chlordane is only one-third as soluble as lindane, it is almost never found in water samples. Yet, it is prevalent in stream sediments. Thus, the patterns of detection that would be expected from use data alone do not occur because of varying chemical properties and analytical capabilities.

Table 6.—Average concentrations (parts per million) of heavy metals in street sweepings compared to shale.

Heavy metal	Street sweepings[1]	Shale[2]
Cadmium	3.4	0.3
Chromium	211	100
Copper	104	57
Iron	22,000	47,000
Lead	1,810	20
Manganese	418	850
Nickel	35	95
Zinc	370	80

[1]*Bradford (1977)*
[2]*Krauskopf (1967)*

recreation now takes place close to home, with the median for day trips to federal recreation areas at 25 miles and 130 miles for overnight trips. McLellan and Siehl (1988) summarized the likely future: "In the decade ahead, recreation managers, researchers and policy makers will find need to cope with rapid change; recreation resource concerns increasingly will be people issues and not resource issues alone. People and society change faster and more erratically, than do the natural resources with which we are professionally concerned." In the following sections, some of the major factors of societal change are examined for their effects on outdoor recreation demand.

Factors Influencing Recreation Demand[3]

A number of factors influence trends in demand for outdoor recreation. O'Leary et al. (1988), Hartmann et al. (1988), and O'Leary (1989) examined several major national recreation studies over the past 30 years to identify which factors may shape the future of outdoor recreation participation. The factors identified include: (1) an aging population with earlier retirement; (2) a decline in available leisure; (3) population growth, particularly in the South, the West, and in rural communities (although at slower rates than in the 1950's and 1960's); (4) increasing immigration, probably bringing new patterns of outdoor recreation; (5) a greater percentage of the workforce represented by women, resulting in more dual-income households with increased discretionary income and less family leisure time; (6) a changing family structure including fewer extended families and more single parent families; (7) higher average education levels; (8) greater health-consciousness; (9) baby boomers entering middle age and becoming important consumers; (10) baby boomers delaying marriage and having children; and (11) rapid economic changes. The implications of these factors are substantial. The typical American family may be smaller with more discretionary income, but they have less free time. These families must plan for shorter, but more frequent, vacations and may choose different activities or do activities in a different way than American families of the past. Some of the major factors which will help shape future recreation demand are discussed below.

Population growth rates and geographic distribution.—The U.S. population is growing at a slower rate than in the past. About 100 million people have been added over the past 5 decades, about 2 million people per year. Wharton Econometrics Forecasting Associates estimates that additional growth over the next 5 decades, to the year 2040, will total slightly over 90 million, an annual average increase of only 1.75 million (Cordell et al. 1989). Immigrants will provide a substantial proportion of this expected increase. Geographic redistributior apart from the well-publicized sunbelt/snowbelt shif shows important changes in residence patterns wit some rapidly growing nonmetropolitan areas. Continue extensive population growth is forecast in coastal state In the 1970's, the growth rate of nonmetropolitan countie exceeded that of central cities and the suburbs, revers ing a long trend. In the 1980's, however, the general tren reversed again with cities and suburbs growing mor rapidly. But a number of nonurban counties continue to grow at a rate more than twice that of the nation. Thes fast growing "exurban" counties are sought by bot retirees and the young because of quality-of-life facto such as scenic and recreational amenities and feder lands, particularly parks or wilderness. Also, the estima ed 40% of the population living within 50 miles of th ocean in 1984 is projected to double by the twenty-fir century.

The post-World War II baby boom continues to hav a profound impact on outdoor recreation. Clawson (198 calculated that, between 1945 and 1970, there were 2 million births above what would have been expected ha pre-World War II birth trends continued. Clawson point out that, by 2010, the earliest of the baby boom genera tion will be 65 years old. Moreover, between 2020 an 2040, the United States will have an unusually large num ber of older persons. While their activities may chang with age, indications are that the baby boom generatio will continue their interest in outdoor recreation, wit greater participation than their parents. If parental pa ticipation affects what children do, the children of tha generation also may be expected to participate at hig levels.

Participation barriers.—Some Americans simpl choose not to participate in outdoor recreation whil others face unwanted constraints. Certain periods of th life cycle (such as early child-rearing and old age) reduc recreation opportunities. Other barriers relate to lifestyle including lack of time, lack of money, disabilities, or poo health. A third set of participation barriers relates t recreation opportunities: lack of appropriate facilitie within an accessible distance, undesirable recreatio places, lack of information about recreation opportuni ties, poor transportation, or lack of convenience (Hart mann and Walker 1989).

Although virtually all segments of the U.S. populatio participate in outdoor recreation to some degree, certai barriers seem to affect some segments of society mor than others. The 10% of respondents to the 1986 Marke Opinion Research poll who said they did not go outdoor for recreation generally were either poor, unmarried, old or physically or mentally disabled. Transportation gener ally is improving nationwide, but the absence of publi transportation may deny outdoor recreation opportuni ties to many people, particularly the elderly or poor i inner cities (President's Commission on Americans Out doors 1987).

The 1985–87 Public Area Recreation Visitor Stud (PARVS) reported that recreation varies by social group especially participation rates (Hartmann and Cordel 1989). Overall, people with low or very high income, the

[3] The material presented in this section is a summary of several unpublished papers prepared for this Assessment. The conclusions of these papers are based on extensive literature reviews and analysis of the Public Area Recreation Visitor Study, which involved interviews with 32,000 users of federal and state recreation areas nationwide. Copies of these papers are on file with the Outdoor Recreation and Wilderness Assessment Group in Athens, Georgia.

Many Americans face barriers to recreation at some time (such as during early child-rearing or old age). Other barriers relate to lifestyle or lack of recreation opportunities.

aged, disabled, blacks, and less-educated recreationists visiting state and federal lands participate significantly less in many outdoor recreation activities than do the rest of the population. The factors underlying differences in participation are complex, interrelated, and not yet fully understood.

Social-psychological influences.—Current social-psychological issues in outdoor recreation include: (1) meeting the **diversity** of demand that exists and that will continue to grow; (2) designing our recreation opportunities to be fair or **equitable** to various segments of society; (3) resolving **conflicts** that ultimately occur among different user groups; (4) dealing with rapid **changes in society**, values, and technology; and (5) contributing to the long-term **benefits** from recreation (such as greater physical and mental health, better productivity, family stability, cultural pride, and identification) while responding to the pressures of short-term events (Schreyer 1988). These social-psychological issues are having greater influence on recreation participation as society becomes more complex. In addition, choosing strategies to achieve balance among the interests these issues represent is increasingly influencing natural resource policy in the United States. As these issues become more acute, demands for outdoor recreation opportunities will take on a different social context, perhaps well beyond the simple one of providing quality outdoor opportunities.

Socioeconomic make-up.—Recent information from the PARVS shows considerable differences in recreation participation depending on demographic make-up. Age, income, race, disability, and sex seem to be among the more influential factors (Hartmann and Cordell 1989).

Aging of the population is a dominant socioeconomic characteristic. Although that segment of the population which is 65 years and older will continue to fall until about 1995, a result of a lower number of births in the 1920's and the Great Depression of the 1930's, more than half of the population will be over 40 by 2000 (Snyder and Edwards 1984). The amount of participation in most forms of outdoor recreation declines with age. This pattern varies depending on the activity as participation rates for some activities, such as walking for pleasure, even increase with age. Generally, the more physical recreation activities show the sharpest decline with age, but many people participate in outdoor recreation into their 70's and 80's (Hartmann and Cordell 1989).

The patterns of recreation participation change with age. Consider camping, for example. Older individuals commonly seek more developed campgrounds, travel further to reach their destinations, and tend to stay longer at the same site than younger individuals (Hartmann 1988). The strong relationship between age and recreation patterns has important implications for the future. Although the influence of cohort effects have been shown for some activities (English and Cordell 1985), the percentages of the total recreating public will likely follow behaviors similar to the current elderly population. These overall percentages will be influenced by the increasing number of older Americans.

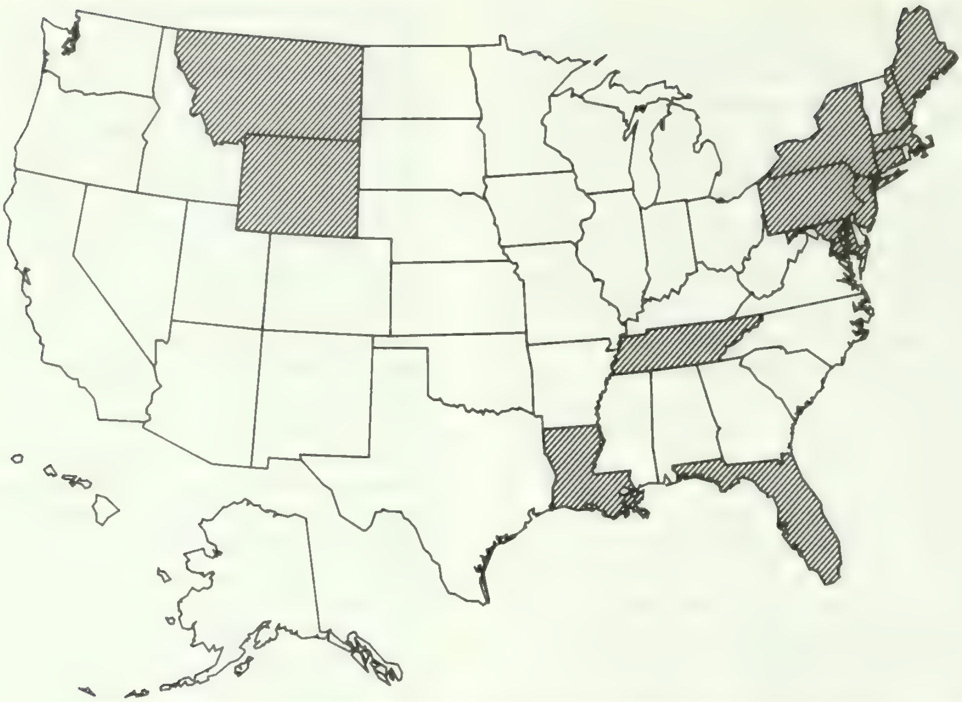


Figure 7.—States reporting acid deposition as a special concern (EPA 1987).

that sulfur dioxide emissions are much higher in the northern hemisphere than southern hemisphere (145.5 million tons per year versus 5.5 million tons, respectively), and are steadily increasing at the rate of 5% annually. Considerable uncertainty exists regarding the relative importance of natural versus man-made nitrogen sources. Some estimates of natural emissions range from 8% to 30% of man-made levels. Natural volatile organic compounds emissions are believed large relative to man-made emissions.

The general geographic pattern of precipitation acidity has changed very little since extensive monitoring began in 1978. Rain and snow acidity for 1985 was highest in the northeastern U.S. The highest acidities, below pH 4.2, were found in the upper Ohio River Valley of eastern Ohio and western Pennsylvania and extended across the Canadian border into southcentral Ontario. Precipitation monitored at remote sites generally has a pH between 5.0 and 5.5 (Roth et al. 1985). Precipitation pH below 5.0 is generally taken as indicative of anthropogenic influences. Roth et al. (1985) note that the amount of deposition measured in precipitation is typically doubled to account for all the different types of deposition when estimating total deposition load. But it is not known whether this rule of thumb is adequate for more arid western locales where most precipitation falls as winter snow.

Linkages to Other Air Quality Problems

It is important to note that while acid deposition is normally viewed as an independent issue, chemical changes occurring in the atmosphere are inextricably related to one another. Problems of ozone depletion, visual impairment, "greenhouse warming," and acid deposition are all interconnected to some degree and all are associated with changes in atmospheric composition. For example, gases which are predicted to modify the distribution of stratospheric ozone (i.e. carbon monoxide, methane, nitrous oxide, and chlorofluorocarbons) are the same gases which are infrared active (greenhouse gases) and are predicted to warm the planet. In addition, increasing concentrations of methane are also predicted to increase ozone in the troposphere and may be responsible for some forest damage that is occurring. Increased atmospheric levels of sulfur may possibly influence climate through enhanced levels of sulfate aerosols. Oxides of nitrogen strongly influence the production of ozone in the troposphere. Many of these chemicals and byproducts of chemical reactions are responsible for gases and aerosols that create visual impairment.

Implications for Aquatic Ecosystems

Lake and stream acidification, which can damage aquatic organisms, may result from natural or man-made causes. Surface water chemistry can change either over the long term or during short episodes such as spring snow melt. Budiansky (1981) noted that the greatest pH shock to lakes occurs when snow melts and runs off. Soil type, hardness of the winter freeze, and amount of dry deposition, together with type and amount of snow and ice, all determine the amount of acidic material that has accumulated over winter and the portion likely to be absorbed by the soil, given its buffering capability. The larger the portion of annual precipitation that falls as snow and the lower the soil buffering capability, the greater the potential for damage due to a pulse of acid-

ity entering a waterbody during snowmelt. Roth et al. (1985) note that springtime acid pulses from snowmelt can severely harm sensitive aquatic ecosystems even if the ecosystems do not permanently acidify.

Middleton and Rhodes (1984) concluded that acid deposition has the potential to contribute to drinking water toxicity. Raw drinking water that is acidic can free toxic metals such as aluminum from the chemical bonds normally immobilizing them to soil colloids. If not adequately neutralized as part of water treatment, acid remaining in water can dissolve toxic metals such as lead from water distribution pipes. Because of the number of areas in the northeastern U.S. using surface water sources for drinking water supplies, the impact could be considerable. Water treatment processes exist for dealing with acidity in raw water and for removing toxic metals during water treatment; however, they are more costly than conventional treatments.

Analysis of historical records by the National Academy of Sciences shows no net acidification of lakes in the past 50 to 60 years in either Wisconsin or New Hampshire, although a few high elevation lakes in the Adirondack region of New York may have suffered some increased acidification. The study noted that quantifying the amount of acidification was not possible at this time. Our understanding of how acid deposition interacts with individual biological, geological, and chemical processes in watersheds and surface waters is considerable. However, major uncertainties exist regarding how individual processes work together over broader areas to result in observed surface water chemistry, according to the Council on Environmental Quality (1987).

New York and Canada allege a much greater impact on high elevation lakes than determined by the National Academy of Sciences. New York considers damage to some 500 lakes in the 6 million-acre Adirondack Forest Preserve to be catastrophic (USDA 1987). About 2 million acres in the Catskill area are also reported to be affected to a lesser extent. By Canada's count, 13 salmon-bearing lakes and 14,000 other lakes in eastern Canada are incapable of supporting fish life (Denton 1987). Studies cited by Roth et al. (1985) report that between the 1930s and 1970s, the percentage of lakes in the Adirondacks with pH less than 5.0 increased from 8% to 48% and the percentage with no fish increased from 10% to 52%. In New England, a study of 95 lakes for which there are historical pH data showed an average alkalinity decrease of 100 milliequivalents per liter between the 1930s and 1960s.[12] Likens (1976) found a clear correlation between geographic areas where precipitation is particularly acidic and areas where lake acidification has occurred. Evidence that other mechanisms could have caused acidification is less convincing.

Roth et al. (1985) summarized the prevailing hypotheses about how lakes and streams subject to acid deposition lose fish populations. Chemical reactions that are dependent upon low pH and that mobilize aluminum, found in most watershed soils, are identified as the primary culprit. Laboratory studies show that fish are injured directly by low pH and indirectly when concentrations of toxic metals result. Both combine to cause reproductive failure in fish and also in organisms in the fish's food chain. Low pH and metal concentrations are thought to be more damaging to aquatic organisms in the spring when many are in early developmental stages. This coincides with onset of snowmelt. Roth et al. (1985) report that the effects of partial acidification due to presence of some natural alkalinity are less well understood.

Implications for Forests

Observations of diminished growth in southern softwoods at low elevations and of visually apparent deterioration of spruce-fir forests at high elevations have heightened concern over the causal factors and the possible role played by air pollution generally, and acid deposition in particular. Budiansky (1981) said that the real question is how the entire forest responds when perturbed by pollution. He noted that the major problem facing vegetation in the Northeast may be ozone, not acid precipitation or sulfur dioxide. Williams et al. (1977) found widespread damage to ponderosa pine, apparently from ozone, in dry regions downwind of Los Angeles and Central Valley. The injury suggested that trees growing in a relatively dry habitat on sensitive soil may be subject to direct damage from air pollution, possibly including acidic deposition interacting with ozone and other pollutants (Roth et al. 1985). Weisskopf (1988), reporting results of a recently released study by World Resources Institute, identified ground-based ozone as the primary cause of death or damage to 87% of the Jeffrey and ponderosa pine on the San Bernardino National Forest near Los Angeles, to white pines in the East, and to major crops in the Midwest and Southeast, including corn, soybeans, wheat, peanuts, barley, and hay. Annual crop losses caused chiefly by ozone are estimated at $5 billion (Weisskopf 1988).

Scientists are not yet able to show that changes in acid deposition will result in changes in forest growth or other measures of forest vigor. The problem is a complex one involving related chemical, physical, and biological systems and requiring a comprehensive, interdisciplinary approach. Current research involves efforts to explain observed forest changes by systematically testing a long list of hypotheses including natural cycles, climate change, pests and disease, forest stand history effects (e.g. exhaustion of residual fertilizer nutrients from previous agricultural use of the land), land management practice effects, and air pollution and acid deposition. A diversity of views exist currently about the impact of acid deposition on forested ecosystems and tree growth, as illustrated by the three sources cited below.

Woods (1987) noted that long-term effects of acid deposition on soils include making elements normally bound by soil particles (such as aluminum ions) more available for plant uptake. Aluminum ions can be concentrated in plant roots to toxic levels. Aluminum ions also reduce the availability of calcium. These changes lead to nutrient imbalances in plants which can cause reductions in productivity well before toxicity causes death. Small changes in the physiology of trees can cause

losses in forest growth. Trees are vulnerable because of long growth cycles. Conifers are especially vulnerable because needles persist for two to four years and are exposed longer to atmospheric deposition.

Brown (1987) noted that the amount of acidity generated by natural sources in the eastern U.S. is much greater than for acid rain. Animal waste and decaying vegetation are responsible for many soil acids. Heavy rains wash these acids into rivers and streams before they can be neutralized by deeper soil layers. Unusual damage to forests is more likely to stem from the combination of natural stresses, such as droughts, frosts, insects, and pathogens coupled with the impact of various air pollutants. Ozone may be a contributor to the problem.

Johnson and Siccama (1983) noted that available evidence does not show a clear cause and effect relationship between acid deposition and forest decline and dieback in the U.S. Given the lack of other causal agents and characteristics of observed dieback, it appears that mortality is probably related to some environmental stress or combination of stresses. Mortality was only significantly correlated with elevation. Several stress factors are related to elevation; it is not currently possible to determine which factors are relevant. Wind speed, exposure to cloud moisture, hydrogen ion concentration, and heavy-metal content of soil all increase with elevation. Drought stress, in combination with predisposing factors related to site conditions, has triggered forest declines in the past. Growth reductions in red spruce during the mid-1960s represent initiation of dieback and decline in these trees. The early and mid-1960s were a period of drought in the Northeast. Available information does not suggest that either sulfur dioxide or ozone plays a major role in spruce decline. Other studies cited by Johnson and Siccama support drought as a prominent factor in observed forest diebacks in North America and Europe.

EROSION

The off-site impacts of sediment were identified in USDA (1987) (the Appraisal) as one of the most significant impacts created by agricultural land management practices on non-federal lands. Erosion reduction is the major focus of the *National Conservation Plan* currently being developed by the SCS in response to the Appraisal. It is also one of the primary water-related impacts of forest and rangeland management on federal lands.

Clark et al. (1985) focused specifically on the off-farm impacts of erosion measured largely by the effects of sediment on water use. The study examined problems caused by sediment and other contaminants carried off by storm water after leaving eroding fields. They found that sediment causes a variety of instream and offstream damages influenced by a complex set of hydrological, physical, chemical, and biological interactions. Christensen and Ribaudo (1987) estimate that sediment in water causes $7.1 billion in damages annually, of which cropland's share is $2.6 billion.

Instream damages are caused by sediment, nutrients and other erosion-related contaminants in streams and lakes and affect aquatic organisms, water-based recreation, water storage facilities, and navigation. Offstream damages occur before sediments reach a waterway, during floods, or after water is diverted from a waterway for use.

Erosion Impacts

Biological impacts of erosion.—Aquatic ecosystems are affected in a variety of ways generally related either to reproduction or respiration. Sediment destroys spawning areas, food sources, and habitat and causes damage to fish, crustaceans, and other aquatic wildlife. Algal growth stimulated by nutrients blocks sunlight while algae are alive; when dead, algal decomposition strips dissolved oxygen from the water rendering respiration impossible. Pesticides and other contaminants from agricultural lands can be directly toxic to fish and to organisms lower in the food chain. Clark et al. (1985) identified agricultural runoff as chronically affecting fish communities in 30% of the nation's waters. Fish kill reports identified such runoff as a major cause of acute episodes.

Although some of these biological impacts are reflected in damage estimates to recreational and commercial fishing, the overall magnitude of impacts cannot be measured because methodology is not available. This is not to say that damages are small or nonexistent.

Recreational impacts of erosion.—All types of water-based recreational activities are adversely affected by erosion-related pollutants. The value of freshwater fishing is reduced because of the demise of valued species and reductions in fish populations. Fishing is also less successful in turbid water because fish have difficulty seeing lures. Many of the same problems affect marine recreational fishing. Many marine species reproduce in estuaries and rivers. As the deterioration of Chesapeake Bay fisheries amply demonstrates, eroded sediments and excess nutrients can lead to severe reductions in fin and shellfish populations.

Boating and swimming are affected because weed growth and siltation physically interfere with recreational activities. Hunting is also affected because many waterfowl depend upon aquatic vegetation and other affected aquatic wildlife for food. Total economic cost of these recreational damages was estimated by Christensen and Ribaudo (1987) at $1.9 billion per year and $544 million for marine fishing.

Erosion damages to water storage.—Damage to reservoirs from sediment is measured by the increasing cost of building and maintaining water-storage capacity. An estimated 1.4 to 1.5 million acre-feet of reservoir and lake capacity is permanently filled each year with sediment. Recent construction of new storage capacity averages 1 million acre-feet annually at a cost of $300 to $700 per acre-foot. Not only is the nation failing to keep up with the rate of sedimentation, but costs of providing additional storage are increasing because low-cost dam sites have already been utilized.

Erosion not only creates major problems on sites where it occurs, annual off-site damages caused by transported sediments exceed $7 billion.

Sediment and nutrients affect the rate of evaporation and transpiration from water bodies. Evaporation is a particularly serious problem in arid regions because more than an acre-foot of storage has to be constructed to provide an acre-foot of yield. Here, suspended sediments and algae may provide a benefit because they reflect much of the solar energy that would otherwise warm the water and enhance evaporation. However, sediments and nutrients are a two-edged sword because they also increase the transpiration rate by stimulating growth of water-consuming vegetation in shallow lake areas.

Lake cleanup is a final cost related to water storage. Lakes are the only water bodies that have suffered a net decline in water quality since 1975. All levels of government are spending substantial amounts for weed control and other cleanup activities. The total annual cost of all these impacts on water-storage facilities is estimated to be $1.1 billion (Christensen and Ribaudo 1987).

Impacts of erosion on navigation.—Sedimentation affects navigation in diverse ways. The major economic cost is maintenance dredging of harbors and waterways. The major environmental cost is disposal of dredged spoil. Prior to the 1950s, spoil was typically disposed of by filling wetlands for further urban development. This practice has largely ceased. Coastal dredged spoil was often barged to sea and disposed offshore. In either case, the dredging process causes temporary turbidity plumes downstream. If these coincide with critical reproduction times, the effects can be just as severe as longer term turbidity. Other costs include accidents and shipping delays. The total annual cost to navigation is estimated to be $680 million annually (Christensen and Ribaudo 1987).

Other instream impacts of erosion.—Soil erosion damages commercial fisheries in much the same way that it affects recreational fisheries. The total cost of other instream impacts of erosion on commercial fishing was estimated to be $409 million (Christensen and Ribaudo 1987).

Soil erosion can also reduce preservation/option/bequest values—the benefits people place upon clean water even though they may never make direct use of the water body. Some studies have shown these values to be even higher than the costs borne by recreational and other uses. Damage to preservation/option/bequest values is not currently estimable with the same accuracy as the other damages. Comparing Clark et al. (1985) and Christensen and Ribaudo (1987), perhaps up to $600 million in damages to these values occurs annually.

Other offstream impacts of erosion.—Water often contains sediment or agricultural byproducts such as dissolved salts in concentrations that are too small to justify treatment. Yet these constituents in water cause increased operation and maintenance costs and more frequent replacement of irrigation equipment. Salt and alkali buildups in pipes can lead to added maintenance and replacement costs. Irrigators using turbid water experience increased costs and reduced yields if fine silt causes a crust to form on the soil surface, impeding water infiltration and seed germination. Christensen and Ribaudo (1987) estimated that the net cost of all these other offstream impacts at $135 million annually.

Flood damages of erosion.—Sediment contributes to flood damages in three ways. First, by settling out in streambeds and clogging waterways, it increases frequency and depth of flooding. Second, because suspended sediment is carried by flood water, the volume of the water/soil mixture is increased, thus raising flood crests. Third, many flood damages are caused by sediment, not by the water itself. There may be long-term damages to agricultural land if floods leave infertile silt behind. The total of all these damages was estimated by Christensen and Ribaudo (1987) to be $888 million per year.

Water-conveyance impacts of erosion.—Some sediment settles out in drainage ditches before water reaches streams. Clark et al. (1985) cited estimates from Illinois that highway department crews annually remove from drainage ditches an amount of sediment equal to 1.4% of the total erosion occurring in the state. The annual cost of controlling weeds and removing sediment from the 110,000 miles of irrigation canals in the U.S. accounts for 15% to 35% of annual canal maintenance costs. Total cost of these damages is estimated to amount to $214 million per year (Christensen and Ribaudo 1987).

Water-treatment costs of erosion.—The cost of treating water before municipal or industrial use increases when raw water is turbid. Sedimentation basins must be built and periodically cleaned out, chemical coagulants must be added, filters must be cleaned more frequently, and special treatment apparatus installed to handle nutrients and other contaminants. For example, nutrients and algae may clog heat exchanger tubes in steam boilers or cooling towers and necessitate increased maintenance costs. Christensen and Ribaudo (1987) estimated that these procedures cost $1.2 billion annually.

Summary

The total estimate of erosion-related damages is $6.1 billion annually of which $2.2 billion is attributable to cropland. If sediment damages are isolated from nutrient, pesticide, and other erosion-related damages, the totals are $3.5 billion of which $1.2 billion is attributable to cropland.

Erosion-related damages not attributable to cropland fall into two categories. The first is erosion from other land management practices. Examples are construction, forestry, grazing, and mining operations. Forestry activities with high erosion potential include road building, timber harvesting operations, and wildfire.

Overgrazing is the primary source of erosion from rangelands. The Appraisal found that at present, 20% of rangeland has erosion exceeding T.[13] The Appraisal concluded that erosion on rangeland is a potential problem on 61% of non-federal range. The assumption made when evaluating this potential was that all range in less than good condition is susceptible to damage. The watershed condition class discussion earlier in this chapter pointed out that 72% of watersheds are either in the Special Emphasis class and need careful management to avoid problems, or in the Investment Emphasis class and need technological and economically feasible investments to restore watershed conditions to a level consistent with watershed management goals. The most significant factor placing these forests and rangelands at risk is the potential for erosion and movement of sediment off-site.

The second category of erosion-related damages not attributable to cropland comes from sediment deposits currently in streams. In some areas where erosion was a major problem such as the abandoned cropland in some parts of the South, streams no longer carry the fresh sediment loads they did at the turn of the century. As sediments were prevented from entering streams either by conversion of the land to forests or more enlightened land management, water energy formerly used to carry sediments has begun scouring old sediment deposits from stream channels and is carrying these previously-deposited sediments downstream. This water action has confounded many studies seeking to demonstrate that land management activities had direct effect on reducing instream sediment concentrations because little reduction in sediment in the water was observed. In some streams, long-buried bridges and other historical artifacts reemerging from silt are offering historians fresh opportunities for studying pioneer and plantation life of the 1700s and 1800s. It may take another 50 to 100 years for these entrained sediments in stream channels to be scoured out and streams returned to the channel configurations they enjoyed before development began.[14]

Clark et al. (1985) concluded that developing an effective, efficient program to control off-farm impacts of eroded materials will be difficult. They called for new regulatory programs that were more accurately targeted at erodible soils and land management practices insensitive to erosion. A key element identified was taking the most seriously eroding lands out of row-crop production or out of production altogether. The Food Security Act of 1985 contained a section dealing with soil conservation measures having several provisions that respond quite closely to the conclusions reached by Clark et al. (1985). Four notable provisions to reduce cropping of erodible land and the environmental implications of land management were (1) creation of the Conservation Reserve Program (CRP), (2) the Conservation Compliance provision, (3) the "Sodbuster" provision, and (4) the "Swampbuster" provision. These provisions only apply to lands with the potential to erode more than eight times faster than new soil can be regenerated. There are 118 million acres of such soils in the U.S., 35 million of which are being managed to prevent erosion in excess of the rate of regeneration (Reichelderfer 1987). It is estimated that 40 to 45 million acres will be enrolled in the CRP by 1990.

The conservation compliance provision is designed to keep erosion low on 35 million acres of erodible lands currently being farmed. Failure to do so causes the farmer to forfeit the right to participate in other farm programs offered by USDA.

The sodbuster provision denies eligibility for USDA programs to farmers who newly cultivate highly erodi-

ble land without using an approved conservation system. The swampbuster provision denies eligibility to farmers to convert wetlands to production of agricultural commodities.

The latter two provisions are designed to discourage conversion of grasslands and river bottomlands which are predominately forest to crop production.

GROUNDWATER CONTAMINATION

Most groundwater supplies in the U.S. are of good quality. In some localities, however, contamination has caused well closures, public health concerns, and economic losses. These problems could spread. The challenge is to prevent localized problems from becoming local crises or regional problems.

The Conservation Foundation (1987) concluded that groundwater protection efforts have been limited at best. Regulatory programs put in place often have failed to exercise much of the statutory authority available. Because many laws were written at different times and for different purposes, they often add up to a program of groundwater protection that is neither coherent nor consistent even if those laws are implemented to the limits of enacted authority.

Groundwater can be contaminated in a variety of ways. EPA (1987) summarized major sources of groundwater contamination reported by states. More than 40 states reported septic tanks, underground storage tanks, and agricultural activities as major sources of contaminants. More than 30 states reported landfills, lagoons, and abandoned waste sites as major sources of groundwater contamination.

Underground storage tanks.—Underground storage tanks were listed as the primary source of groundwater contamination by 11 states. These are Alabama, Alaska, Florida, Michigan, Montana, New Jersey, New York, North Carolina, Pennsylvania, South Dakota, and Virginia. The Conservation Foundation (1987) provides additional detail on the magnitude of problems associated with underground tanks by citing a recent Congressional Research Service report. That report estimated there are between 5 and 10 million underground tanks of all kinds (EPA's estimate is 3 to 5 million), of which 1.5 million tanks contain petroleum or hazardous substances (1.4 million by EPA's estimate). Most existing tanks are made of carbon steel, unprotected from corrosion, and range in size from 10,000 to 50,000 gallons. Some fiberglass tanks are also used, but they tend to be smaller, averaging 10,000 gallons. The Congressional Research Service estimated that 25% to 30% of tanks containing petroleum products may be leaking (a limited EPA survey in 1986 found 35% leaking). Vehicle filling stations accounted for the majority of leak locations. Other studies found that the majority of leaks occur from operating tanks and not abandoned ones. Leaks of solvents are proportionately more prevalent than leaks from petroleum tanks. Corrosion of tanks and associated pipes and fittings accounts for 90% of the leaks according to the Conservation Foundation (1987).

Septic tanks.—Failure of septic systems was reported as the primary cause of groundwater contamination by nine states, including Arkansas, Delaware, Illinois, Kentucky, Maine, Maryland, Nevada, Ohio, and Tennessee. Contamination from this source is not a new problem; however, shifts in housing patterns and land use, particularly increasing housing densities in suburbs, have made septic system discharges a more prevalent problem. About one-fourth of American homes (20 million homes) use on-site sewage disposal; most of these are east of the Great Plains.

Septic systems are far more popular than cesspools or pit privies. A 1980 study cited by Conservation Foundation (1987) reported that up to one-third of the systems were operating improperly. Groundwater pollution by nitrates, phosphates, heavy metals, other inorganics, and toxic organics often used as system cleaners, result when systems are not operating properly. The efficiency of a septic tank decreases over time, even with proper maintenance (periodic removal of sludge), because of a buildup of film on the outside of drains or clogging of the drainage bed material. One study reported by the Conservation Foundation (1987) found that 75% of septic system failures can be attributed to overloading the drain field with sludge. The cleaning and sludge removal process often uses chemicals such as trichloroethane, benzene, or methyl chloride, to dissolve sludge in tanks and drain fields—chemicals that should not come in contact with groundwater. Widespread use of these chemicals on Long Island in 1979 (an estimated 400,000 gallons total, many applied by homeowners themselves) resulted in closure of many public and private wells (Conservation Foundation 1987). Careful location, construction, and maintenance provides some measure of protection against groundwater contamination.

Agricultural activities.—Agricultural activities were cited as the primary source of groundwater contamination by 6 states including Arizona, Arkansas, California, Connecticut, Hawaii, and Iowa. The primary contaminants are nutrients from fertilizers, livestock waste disposal, and pesticides.

Fertilizer use in the U.S. has grown drastically, rising 300% between 1960 and 1980. Nitrogen fertilizer applications have quadrupled over the same period. In addition to the large increases in fertilizer applications to cropland, large amounts are also applied in urban areas to turf and gardens. The Conservation Foundation (1987) recounts results of several studies in Wisconsin, Nebraska, and Iowa linking increases in nitrate concentrations in well water to heavy usage of nitrogenous fertilizers.

Animal wastes are another source of nutrients and bacteria. Feedlots are often viewed as major sources of contamination but manure disposal on individual farms can also cause problems. Southeastern Pennsylvania is one of the most concentrated areas of dairy farms in the nation. The volume of manure created and the small size of the typical dairy farm combine to create manure disposal problems. Application rates exceeding 2 tons per acre per year are not uncommon; at a 5% nitrogen content, this equates to more than 200 pounds of nitrogen

per acre annually. Runoff from fields contaminates surface waters and leachate percolates to groundwater. Because of the limestone geology of Southeastern Pennsylvania, there are many channels and solution cavities providing speedy access of percolate to aquifers which exacerbates manure disposal problems. The Conservation Foundation (1987) recites manure disposal problems associated with beef production in Colorado and poultry production in Delaware. Methods of solving nutrient contamination problems from agricultural operations include matching fertilizer requirements and timing of applications more closely with actual crop needs and collecting, storing, and treating livestock and poultry wastes before applying them to fields.

Pesticide applications were the second concern related to agricultural operations. The Conservation Foundation (1987) reported that herbicide use has grown by 200% between 1966 and 1981 as chemicals replaced mechanical cultivation for controlling weeds. In 1982, 91% of all U.S. cropland farmed was planted with row crops and 44% of those acres had herbicides applied. However, 85% of the herbicides and 70% of the insecticides were applied to only four crops—corn, cotton, soybeans, and wheat. The two most heavily used substances are the herbicides alachlor and atrazine; accounting for 25% of the total national usage. The two states using the largest quantities are Iowa and Illinois, which account for 21% of total usage. Soluble formulations of pesticides and those products designed to kill soil pests have the greatest potential for contaminating groundwater. Problems with groundwater contamination can be minimized by using formulations that do not migrate through the ground, by taking greater care in where, when, and how pesticides are applied, and by combining pesticide usage with other non-chemical techniques in a program of integrated pest management.

Landfills.—Five states identified landfills as the primary source of groundwater contamination. It is estimated that between 15,000 and 20,000 municipal dumps and sanitary landfills exist in the U.S. An exhaustive list is not available; the actual number could be as high as 40,000. Four out of five facilities are small, handling less than 100 tons of waste daily. Two hundred seventy five million tons of municipal solid wastes are disposed of in landfills annually. Older landfills and open dumps were often uncovered, unlined, and located with no consideration of their potential for contaminating groundwater. In addition, many landfills were located on marshlands, abandoned gravel pits, and old strip mines. Such sites are susceptible to groundwater contamination if infiltration flowing through the disposal site is a source of groundwater recharge and if underlying soils are sufficiently permeable to allow leachate to enter the groundwater system. Percolation of leachate from landfills is inevitable unless the site is completely sealed on all sides. Few are. Groundwater contamination from landfills can be minimized by improved design, construction, operation and maintenance. Design considerations should always include hydrogeology of the landfill location, area to be served, and types of wastes. The use of liners and covers, as well as collection and treatment of leachate, further reduce the potential for groundwater contamination (Conservation Foundation 1987).

Hazardous wastes.—Hazardous wastes, while a major cause of concern by 29 states, were a primary concern of only three states. About 5,000 sites in the U.S. are treating, storing, and disposing of hazardous wastes. The largest number of sites are in the Great Lakes region followed by the Southeast and Southwest. As of June 1986, 888 abandoned hazardous waste sites were listed or proposed for listing on the National Priorities List and thus targeted for federally-funded cleanup under the Superfund. Seventy-five percent of the sites on the National Priorities List have documented groundwater contamination problems. The most commonly found substances include trichloroethane, lead, toluene, benzene, PCBs, chloroform, phenol, arsenic, cadmium, and chromium.

The potential for contaminating groundwater can be reduced in several ways. Careful siting and operation of treatment, storage, and disposal facilities can minimize the potential for unforeseen problems. Liners and leak detection systems can be installed to reduce the possibility that contaminants can escape unnoticed. Enclosing more hazardous substances in concrete, glass, or ceramic vessels reduces potential for leakage. Alternative disposal techniques such as incineration or waste solidification may have less environmental hazard than burial. Finally, reducing the generation of hazardous wastes through modifying plant processes, recycling, detoxifying, drying, or substituting nonhazardous materials should also be examined. These steps provide the most attractive long-term methods for reducing the problem (Conservation Foundation 1987).

A Groundwater Protection Strategy

The 1987 National Groundwater Policy Forum (Conservation Foundation 1987) concluded that the nation must adopt a much more aggressive policy of groundwater management if the resource is to be adequately protected for current and future users. Because the problem is complex, a highly coordinated attack is required with participants from all levels of government and industry. Partnerships must be forged to achieve the common goal of protecting the groundwater resource. Four principles should guide the development of a protection strategy: (1) active management is required to meet human and ecological needs; (2) contamination should be prevented wherever possible because of the technical difficulties and costs of cleanup; (3) degradation of the most valuable aquifers and critical water supplies must be prevented; and (4) the strategy must recognize the wide variation across the country in the nature, vulnerability, and use of groundwater, and in state and local governments' ability to manage it.

The Policy Forum recommended a new environmental partnership to avoid creation of a new and burdensome bureaucracy. Partners should include federal, state, and local governments, private industry, and public interest groups. The Forum recommended that the part-

nership be structured so that a clear national mandate is set forth while ensuring that states, assigned the lead role, have ample room to operate. Two key aspects from the states' perspective are (1) consolidating groundwater laws and programs under the jurisdiction of a single state agency to facilitate a coordinated approach to problem prevention and solution; and (2) having substantial flexibility to design programs that respond to specific local needs. The federal government's role was envisioned as balancing national consistency with the reality of geographic differences. Ten components of a prototype state groundwater protection program were identified:

1. Comprehensive mapping of aquifer systems and their associate recharge and discharge areas;
2. Anticipatory classification of aquifers;
3. Ambient groundwater standards;
4. Authorities for imposing controls on all significant sources of potential contamination;
5. Programs for monitoring, data collection, and data analysis;
6. Effective enforcement provisions;
7. Surface-use restrictions to protect groundwater quality;
8. Programs to control groundwater withdrawals to protect groundwater quality;
9. Coordination of groundwater and surface-water management; and
10. Coordination of groundwater programs with other relevant natural resource protection programs.

Other institutional arrangements to implement the prototype program are discussed by the Conservation Foundation (1987).

SUMMARY

The three major water-related environmental problems identified in this Assessment are acid deposition, erosion, and groundwater contamination. All stem from externalities—resource management actions that fail to take full account of the potential disruption to ecosystems caused by pollutants. Pollutants are nothing more than resources out of place. When removed from their proper place, these resources cause ecosystems to change in ways not desirable to society.

There are several steps in solving problems created by resources out of place. The first is deciding how we want ecosystems to function. This step involves deciding how much ecological change society deems acceptable. "No change" is rarely a viable option because resource use invariably changes ecosystems in one way or another. The second step is identifying mechanisms by which unacceptable ecosystem changes are occurring. With erosion, this step has been answered more fully than for acid deposition or groundwater contamination. The third step is devising a way to alter mechanisms causing unacceptable ecosystem changes.

Tools to help solve problems include market-oriented processes and institutional processes, such as regulations or legislation. Today's society appears to prefer using market forces instead of institutional processes. But if market pressures are demonstrated to be ineffective, society has no qualms about insisting on using institutional processes. Dickering over ways, means, and costs via the political system is the way our society achieves consensus on attacking problems.

This section of Chapter 2 focused specifically on the second step in a general process outlined above. The major causes of acid deposition, erosion, and groundwater contamination have been reviewed with the objective of describing the sources and scope of the problems. The abbreviated discussions of acid deposition, erosion, and groundwater contamination presented are only abstracts of the highlights from literature cited in this chapter. Interested readers should consult the literature cited as they contain a wealth of more detailed information on the subjects.

CONDITION AND DISTRIBUTION OF THE NATION'S WETLANDS

PRESENT DISTRIBUTION OF WETLANDS BY SIZE AND REGION

There are 90 million acres of wetlands in the lower 48 states or about 5% of the total land area. Of all wetlands, 95% are inland freshwater wetlands and 5% are of the coastal saltwater type.

Wetland ecosystems are especially prevalent in Alaska. That state alone has approximately 200 million acres of wetlands (60% of its land area); over twice the total of the lower 48 states. Outside of Alaska, the largest concentrations of wetlands are found in the North and South. Those located in the South are primarily caused by sedimentation where soil is eroded from seacoasts or riverbanks and deposited behind barrier islands or onto alluvial plains. Wetlands caused by glaciation are found in the North and scattered throughout the West.

Glaciers form wetlands in three ways: large blocks of ice melt to form depressions; rivers are dammed by glacial debris; and lake beds are formed by scouring action. Other causes of wetlands are beaver dams, human activity, wind erosion, geologic movement such as sinkholes, and freezing/thawing. Alaska's wetlands are caused by the last category—soils near one surface thaw on a seasonal basis but their moisture is prevented by permafrost from entering the water table. Wetlands are especially prevalent in the upper Midwest, the lower Mississippi River valley, and along the Atlantic Ocean and Gulf of Mexico (fig. 8 and table 7).

Throughout history, wetlands have been considered wastelands that could only be put to productive use if they were drained or filled. Within the last 200 years, over 50% of the wetlands in the lower 48 States have been converted to other uses such as agriculture, mining, forestry, oil and gas production and urbanization. Wetland losses are continuing today at an alarming rate, estimated at 350,000 to 500,000 acres annually.

The most extensive inland wetlands losses have occurred in Louisiana, Mississippi, Arkansas, North

Figure 8.—Distribution of wetlands (OTA 1984).

Table 7.—Geographic distribution of wetlands, by type

Wetland type	Water resource region
Inland freshwater marsh	South Atlantic-Gulf Souris-Red-Rainy Texas-Gulf
Inland saline marsh	Lower Colorado Great Basin Pacific Northwest California
Bogs	South Atlantic-Gulf Great Lakes Ohio Upper Mississippi Lower Mississippi
Tundra	Alaska
Shrub and wooded swamps	South Atlantic-Gulf Great Lakes Ohio Upper Mississippi Lower Mississippi Texas-Gulf
Bottomland hardwoods	South Atlantic-Gulf Lower Mississippi Texas-Gulf
Coastal salt marshes	New England Mid-Atlantic South Atlantic-Gulf Texas-Gulf Pacific Northwest California
Mangrove swamps	South Atlantic-Gulf Texas-Gulf
Tidal freshwater wetlands	Mid-Atlantic South Atlantic-Gulf Texas-Gulf

Source: After OTA (1984)

Carolina, the Dakotas, Nebraska, Florida, and Texas. Estuarine wetlands losses have been greatest in California, Florida, Louisiana, New Jersey and Texas.

Results of these wetlands losses have been devastating. In many coastal areas where estuarine wetlands losses are high, urbanization and increased ground-water withdrawals have resulted in saltwater contaminating public water supplies. In Chesapeake Bay—the largest estuary in the U.S.—sea grass, wild celery beds, and tidal wetlands have been declining since the 1960s. In the upper Bay, they have almost disappeared. Canvasback ducks that thrived on the wild celery beds at the turn of the century are rarely found in the upper Bay and their population in the lower Bay is down significantly.

In North Carolina, forestry and agriculture have played an important role in the loss of considerable evergreen forested and scrub-shrub wetlands known as *pocosins*. Most of these areas were transferred to large-scale agriculture even though difficult to drain. In addition to extensive land clearing and ditching, large quantities of fertilizers and lime must be added to these wetlands to keep them fertile and productive. Runoff carries nutrients which degrade the water quality of adjacent estuaries. Development of pocosins for intensive softwood silviculture changes their character but the lands remain wetlands. In EPA (1987), 11 States reported that wetlands were a special concern (fig. 9).

INFLUENCE OF WETLANDS ON REDUCING PEAK FLOW RATES

Some wetlands have been used to help reduce flood damages to developed areas. Because wetland hydrology is extremely complex and variable by wetland type, not all such areas can provide temporary detention of runoff or a time lag between entering and exiting a wetland.

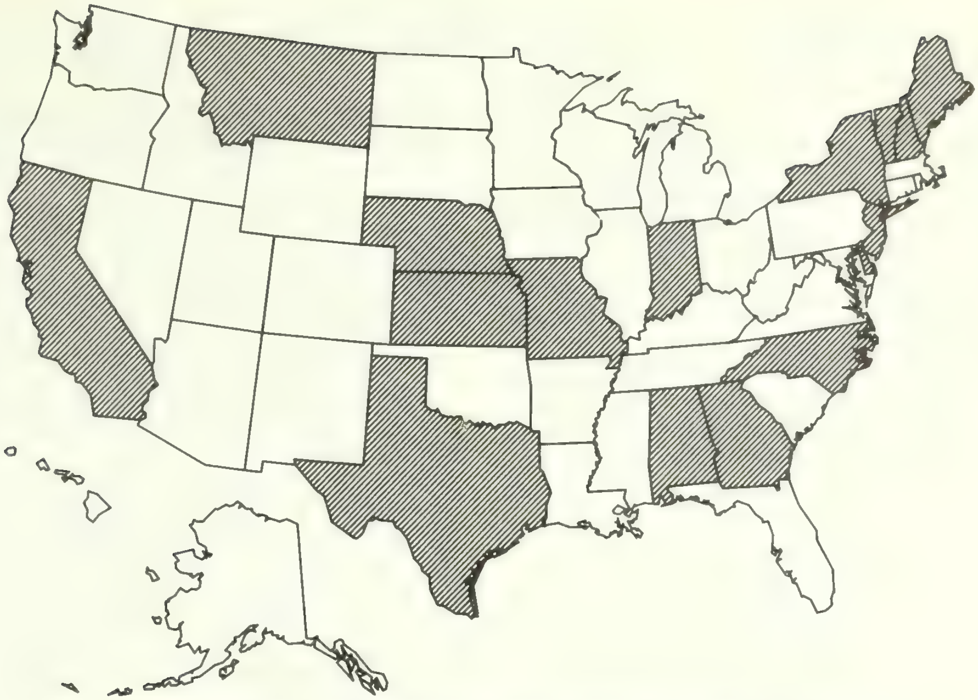


Figure 9.—States reporting wetlands loss as a special concern (EPA 1987).

When wetlands can provide temporary detention and a lag in runoff timing, they help reduce flood damages by lowering the peak flow rate of flood waters. A high peak flow for a short period of time tends to cause more damage to developments than a lower peak flow rate over a longer period of time. A second way that wetlands can help reduce flood damages is by slowing flood water velocities. When the velocity drops, flood waters experience a reduction in their ability to carry debris and sediment. Debris such as tree limbs, shopping carts, and sediment are responsible for a significant portion of flood damages both by crashing into objects and breaking them, as well as by being deposited in developed areas necessitating expenditures for cleanup. A third way that wetlands can help reduce flood damages is by helping to siphon off floodwaters and carry them around or away from developed areas. The classic example of how wetlands help in this way is found in southern Louisiana. When the lower Mississippi River reaches a certain flood stage, the U.S. Army Corps of Engineers diverts a portion of the Mississippi River around Baton Rouge and New Orleans through the Atchafalaya Swamp to the Gulf of Mexico. Also, the Bonnie Carrie Spillway above New Orleans can be opened to divert more of the river's flow across several miles of marshland to Lake Pontchartrain and through the Lake's outlet to the Gulf. A fourth way that wetlands can help reduce flood damages applies specifically to coastal wetlands. They help absorb the energy of the tidal surge accompanying hurricanes.

When development encroaches on coastal wetlands, periodic major storms can cause extensive damages. An example from southern Louisiana illustrates the point. The Pearl River is the border between eastern Louisiana and southern Mississippi. The lower 15 miles are a classic freshwater bottomland hardwood and cypress swamp, nearly 5 miles wide at points. Interstate 10 cuts across the lower part of the swamp forming a 5 mile-long dike punctured by 5 bridges and several culverts. In recent years, major floods on the Pearl have backed up behind the I-10 roadway causing damage to residential areas rimming the swamp, flowing over the roadway closing I-10, and threatening to wash out the roadbed.

INFLUENCE OF WETLANDS ON MAINTAINING WATER QUALITY

Richardson (1988) concluded that some wetlands are valuable from an ecological perspective because of their ability to transform, store, and recycle nutrients and sediments. By temporarily or permanently retaining pollutants such as toxic chemicals and disease-causing micro-organisms, wetlands can improve the quality of water that flows over and through them. Some pollutants that are trapped in wetlands may be converted by biochemical processes to less harmful forms. Some pollutants may remain buried; others may be taken up by wetland plants and either recycled within the wetland or transported from it. By temporarily delaying the release of nutrients until the fall when marsh vegetation dies back, wetlands can prevent excessive algal growth in open-water areas in the spring and summer. This characteristic led some communities in coastal areas to move their wastewater effluent pipes from rivers and offshore areas to wetlands where marsh vegetation can remove the nutrients. Not all types of wetlands have these characteristics.

REGULATIONS INFLUENCING WETLANDS CONVERSIONS

Section 404 of the Clean Water Act gives the U.S. Army Corps of Engineers authority to issue permits for the discharge of dredged or fill material into the navigable waters at specified disposal sites. This program is discussed in more detail in Chapter 8.

Inland freshwater wetlands comprise 95% of the remaining wetlands resource in the U.S. and more than 90% of the estimated 300,000 acres of freshwater wetlands lost each year to development. Many of the losses involve drainage without a discharge which is not regulated by the 404 Program. The swamp buster provision of the 1985 Farm Bill should help mitigate this problem by discontinuing subsidies to farmers who drain and plant wetlands.

Approximately 11,000 permit applications under Section 404 are processed by the Corps of Engineers each year. The EPA , the Fish and Wildlife Service (FWS), and the National Marine Fisheries Service all have a role in the permit review process as do states and other interested parties. One role of EPA is to determine if the proposed use will have "an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas, wildlife, or recreational areas)." If so, they can prohibit or restrict proposed site use.

As a result of this process, the Corps of Engineers annually denies about 3% of permit applications. About one-third of the permits are significantly modified from their original application and about 14% of permit applications submitted each year are withdrawn by the applicants. The Office of Technology Assessment (OTA 1984) estimated that these denials, modifications, and application withdrawals save 50,000 acres of wetlands every year.

NOTES

1. The material in this section is drawn largely from Foxworthy and Moody (1986).

2. Precipitation variability is even more extreme than depicted in figure 1 because of gauging station locations. Gauging stations are typically located at or near settlements to facilitate daily reading of the instruments. In mountainous areas, settlements are nearly always situated in valley bottoms where precipitation is often much lower than on the slopes or tops of the nearby mountains.

3. See the discussion by Reisner (1986).

4. Organic Administration Act of June 4, 1897 (Ch. 2, 30 Stat. 11, as amended; 16 U.S.C. 475).

5. The information in this section is drawn largely from "Water Availability Issues" in USGS (1984; p. 36–45).

6. Dr. James B. Gregory, Associate Professor of Forest Hydrology at North Carolina State University, brought this example to my attention.

7. The discussion is drawn largely from Foxworthy and Moody (1986).

8. Information in this section is drawn largely from three sources: Anon. (1984) provided an overview; Smith et al. (1987) reports trends based upon information data from two stream sampling networks operated by USGS; and EPA (1987), a biennial report to Congress.

9. The discussion that follows was drawn largely from EPA (1987).

10. Funding needs for waste treatment was also listed as a concern by 10 states. The funding concerns reflect expectations of additional funding cutbacks; because they have not yet occurred, the funding cutbacks were not analyzed in this report.

11. The discussion in this section is drawn largely from Council on Environmental Quality (1987), unless information is otherwise cited.

12. Alkalinity is a measure of the acid neutralizing capability of a waterbody. When a strong acid, such as sulfuric, enters the water, the natural alkalinity in the water buffers the acid added by chemically neutralizing it. In so doing, some of the alkalinity is consumed. So, a decline in alkalinity shows that acid entered the waterbody and was neutralized.

13. T is a measure of the erosion potential of the soil and its associated vegetative cover. Its use to evaluate land condition is explained more fully in USDA (1987).

14. Personal conversation with Wayne Swank, Forest Service Research Hydrologist, during the review of the water aspects of the *South's Fourth Forest* (USDA Forest Service 1988).

CHAPTER 3: THE DEMAND SITUATION FOR WATER

HISTORICAL OVERVIEW OF DEMAND FOR WATER

The emergence and growth of the United States as an industrialized nation has been closely tied to water use. Settlement along the Atlantic Coast was initially tied to use of water for transportation—settlements quickly sprung up at good harbors. Commercial fishing and trade were early water-based stimulants to local economies. Inland waterways became transportation corridors for trade in both raw materials and finished goods. In the West, Spanish settlers and missionaries established modest irrigation works in the 17th century. By the early 1800s, settlements were well established at many locations where favorable conditions of flow and topography permitted waterpower to be harnessed for milling products such as grain, logs, and wool. Development of the steam engine in the early 1800s suddenly freed industries from having to locate on stream banks to secure waterpower and the Industrial Revolution was underway. Mormon settlers began irrigation in 1847. Ranchers and miners in the West were also diverting water in the mid-1800s.

After being a constraint on growth for 200 years, water was much less so for the rest of the 19th century. Instead, fuel for the steam engine became the primary constraint. Wood and coal instead of waterpower fueled industrial expansion into the early 1900s. Also during this period, railroads rose to prominence as a method of transportation, thus making the country much less reliant on boats and barges and navigable streams and harbors. Water for drinking and water for waste disposal were the two uses that increased most rapidly to the beginning of the 20th century.

By the beginning of the 20th century, civilization had tainted most coastal waters and many inland streams. Rapid population growth of cities and increasing concentrations of industry combined to overtax the ability of the nation's water resources to meet all needs. Typhoid epidemics erupted in a number of cities along the East Coast around the turn of the century. The cause was finally determined to be contaminated drinking water. Practical methods of chlorinating drinking water had not yet been discovered. Rural and urban developments in the floodplain of major streams such as the Mississippi, Missouri, and Ohio Rivers, both contributed to the cause of flooding and incurred damages due to flooding. Flood control structures—dams and levees—were fragmentary. In the Midwest and West, many areas could not sustain settlement because insufficient water was available for crops or animal husbandry. Securing the coal and wood needed to fuel the economic engine of the U.S. led to resource extraction practices that fouled waters with sediment and acid. Land reclamation and forest regeneration practices had not yet been developed.

By the middle of the 20th century, the country had begun to remedy many water and related land resource problems. Local, state, and federal agencies led an assault

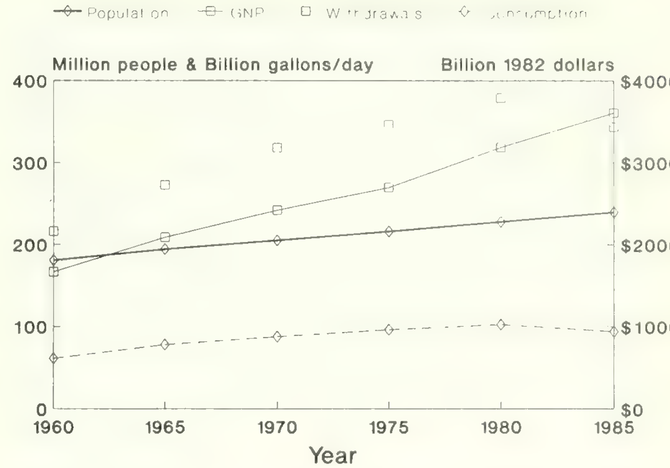


Figure 10.—Rates of increase in GNP, population, and water withdrawals, 1960–1985.

on the problems. Structural approaches to solving water resource problems were favored. The Army Corps of Engineers improved navigation and controlled flooding with locks, dams, dredging, levees, and other works. The Bureau of Reclamation built dams and irrigation structures to water the West. The Forest Service and SCS developed and installed land management practices to keep soil in place, thereby preserving clean water. The Tennessee Valley Authority began economic redevelopment of the southern Appalachians—a massive demonstration of how water resources could be better harnessed for economic development. Local and state governments installed water and waste treatment facilities to render potable supplies safe and remove suspended solids from waste flows.

The demands for water today stem largely from this history of developing water resources. The inertia created by using water resource development to drive economic development continues to affect demand for water today and will for years to come. Trends in water withdrawals and consumption through the 1960s and 1970s show an inexorable climb in total use, marching lockstep with increases in gross national product (GNP) and population (fig. 10).

But by the early 1970s it became clear that while prior developments had, to a great extent, solved problems of water flow volumes, much remained to be done about problems of water quality. Public Law 92–500 and subsequent amendments and related water quality legislation provided the added momentum needed to preserve pristine water quality where it existed and to clean up fouled water to fishable and swimmable levels. The legislation provided a major shift in the long-run trend of ever-increasing withdrawals and consumption. The added cost of waste treatment imposed by the legislation made water conservation and recycling much more cost-effective than it had been in the past. Recent water withdrawals and consumption information (Solley et al. 1988) shows that water quality legislation has also had

a significant effect in retarding growth in demand for withdrawals and consumption (fig. 10).

This chapter reviews historical trends in water demand and projects those trends into the future. Water withdrawals and consumptive use are both referred to as "demand" in this chapter. In later chapters, demand analyses will use consumption because it is the more limiting form of water use.

Historical data on water withdrawals and consumption is summarized from USGS (MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972 and 1977, Solley et al. 1983, and Solley et al. 1988). Projections of withdrawals and consumption are presented for the years 2000 to 2040 based on USGS data from 1960 to 1985. Water demand projections made in other studies published since 1960 are reviewed and comparisons of data recently collected with previous projections are made.

HISTORICAL DATA ON WATER WITHDRAWALS AND CONSUMPTION

National trends in withdrawals and consumption.—The USGS reported estimates of water use in the United States at five-year intervals since 1950 (MacKichan 1951). The most recent data available is 1985 (Solley et al. 1988). Withdrawals in 1960 totaled 216 bgd and consumption was 61 bgd.[1] By 1985, withdrawals totaled 343 bgd and consumption 93 bgd, reflecting increases of 59% and 52% respectively (fig. 11).

National trends by water use.—Increases in total withdrawals and total consumption obscure interesting trends in the six major categories of water use and over time. Water uses examined in this report include thermoelectric steam cooling, irrigation, municipal central supplies, industrial self-supplies, domestic self-supplies, and livestock watering. Trends in freshwater withdrawals vary by use. Withdrawals for municipal central supplies rose 78% from 1960 to 1985 while withdrawals for industrial self-supplies dropped 21% (table 8).

Consumption trends also vary by use. Consumption by thermoelectric steam cooling rose 1840% from 1960 to 1985 while consumption by irrigation only rose 42% (table 9). Detailed tables of withdrawals and consumption by type of use are presented in Appendix A. Detailed discussion of trends by use category are presented later in this chapter when projections are discussed.

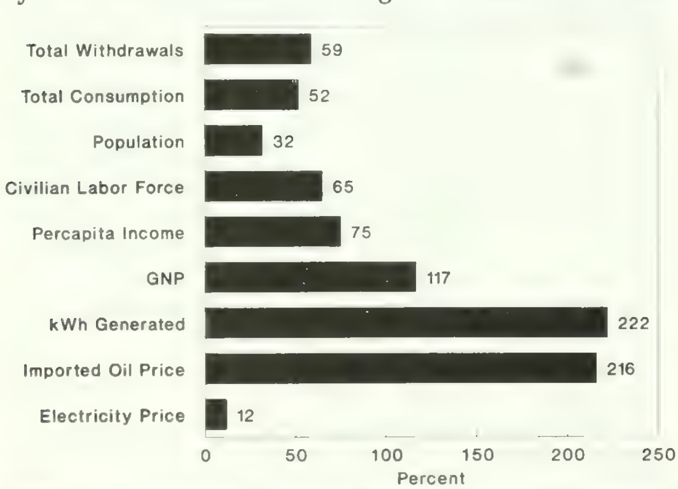


Figure 11.—Increases in withdrawals, consumption, and related variables from 1960 to 1985.

National trends by water source.—Withdrawal and consumption trends vary by source of water. From 1960 to 1985, groundwater withdrawals rose 81% and surface water withdrawals rose 53%; however, wastewater withdrawals declined 5%. The latter figure is particularly noteworthy because in the early 1970s, wastewater reuse was strongly encouraged. The reduction apparently only counts water withdrawn from conveyance structures after municipal wastewater treatment. One policy implemented by regulations arising from the Clean Water Act was to charge industries the full cost of treating industrial waste flows sent to municipal treatment plants. It now appears that industrial users adopted internal recycling strategies to reduce their waste flows and thus municipal waste treatment fees. Data showing industrial self-supplied withdrawals dropping 21% and consumption rising 39% are consistent with significant increases in internal recycling.

Regional trends in withdrawals and consumption.—Trends in freshwater withdrawals between 1960 and 1985 also varied among geographic regions (table 10). Withdrawals in the South and Rocky Mountains rose 89% and 75% respectively. This doubled the increases in the North and Pacific Coast, which were 40% and 32% respectively. Over this period, Censuses of Population and Manufacturing both reported population and industrial growth in the South and West and declines in the North. Water withdrawals were similarly affected. The lower percentage increase in withdrawals along the Pacific Coast reflects the fact that major increases in population and industry occurred in a water-short area (e.g. in Southern California) relying heavily on imports from other hydrologic basins.

Consumption trends by region show a different story. Consumption in the North increased 132%, far eclipsing increases in the South (68%), Pacific Coast (49%) and Rocky Mountains (37%). Because the North is more heavily industrialized than other parts of the United States, it shows a larger increase in consumption than the other regions. Irrigation is the primary component of consumption in the other three regions. There have been smaller percentage increases in consumption in irrigation than in the industrial sector.

PROJECTED DEMANDS FOR WATER

The projections from 2000 to 2040 presented here are the result of Forest Service analyses conducted especially for this Assessment. Projections *are not* the Forest Service interpretation of a "most likely" scenario. The projections *are* a statement of demand levels in 2040 if recent trends in demand for water continue. Projections of withdrawals and consumption are intended to suggest future demands if water resource management continues as it has from 1960 to 1987. However, some demand pro-

Table 8.—Total freshwater withdrawals (million gallons per day) in the United States for 1960 to 1985, by water use and source, with projections of demand to 2040

							Projections				
Water use and source	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**2000**	**2010**	**2020**	**2030**	**2040**
Thermoelectric steam cooling											
Groundwater	920	1100	1400	1400	1600	610	700	700	690	680	680
Surface water	73100	90500	118300	129600	146800	129800	156700	174500	192200	209900	227600
Total Thermoelectric	74000	91600	119800	131000	148400	130400	157400	175200	192900	210600	228300
Irrigation											
Groundwater	30400	41600	45250	57100	61200	56300	55600	58300	60900	62650	64200
Surface water	54000	74400	81700	85000	90400	85800	86600	92900	99100	104210	109100
Wastewater	560	500	370	370	280	450	290	260	200	200	200
Total Irrigation	84900	116500	127300	142500	151900	142500	142500	151500	160200	167100	173400
Municipal central supplies											
Groundwater	6300	8100	9500	10800	11700	14600	20100	24100	28200	31600	33700
Surface water	14200	15700	17900	18800	22300	21900	30500	34600	38500	41640	43500
Total Municipal	20500	23800	27400	29600	34000	36500	50600	58700	66700	72300	77100
Industrial self-supplies											
Groundwater	6000	6800	8000	9700	10300	6100	5600	6400	7340	8310	9340
Surface water	27200	29700	31200	28600	28700	20200	21700	23600	25420	27220	28960
Wastewater	70	140	150	170	190	150	300	400	420	470	500
Total Industrial	33300	36600	39300	38500	39200	26450	27600	30400	33200	36000	38800
Domestic self-supplies											
Groundwater	1840	2200	2500	2670	3260	3250	4300	4800	5250	5600	5800
Surface water	160	120	120	130	180	60	80	60	40	30	30
Total Domestic	2000	2320	2620	2800	3340	3320	4380	4860	5290	5630	5830
Livestock watering											
Groundwater	825	1000	1070	1250	1200	3020	1500	1600	1690	1750	1780
Surface water	675	740	800	900	970	1450	1180	1260	1330	1380	1410
Total Livestock	1500	1740	1870	2150	2170	4470	2680	2860	3020	3130	3190
Total groundwater withdrawal	46285	60800	67720	82920	89260	83880	87800	95900	104070	110590	115500
Total surface water withdrawal	169335	211160	250020	263030	289350	259210	296760	326920	356590	384380	410600
Total wastewater withdrawal	630	640	520	540	470	600	590	660	620	670	700
U.S. Total Withdrawals	216200	272400	318300	346600	379000	343700	385200	423600	461300	494800	526600

NOTE—The sum of totals by use and by water source differ because of independent rounding of intermediate sums.

Source: Data for 1960 through 1985 from U.S. Geological Survey Circulars, except for 1985 irrigation numbers. These are from the Soil Conservation Service, modified by additional non-agricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

jections lead to environmental, social, and economic implications at odds with the nation's goals. Consequently, these demand projections are a description of what planners call the "without" condition; the basis for evaluating the impacts of possible changes in water resource management to better achieve environmental, social, and economic goals for the future.

In the course of analyzing demand data, it became clear that simple linear extrapolation of data from 1960 to 1985 did not fit as well as semi-logarithmic or logarithmic curve forms. Linear trends usually had the 1985 datum well beneath the trend line and the 1980 datum on or slightly beneath the line. The Water Resources Council (1978) projected that the *rate of increase in demand* from most uses would decline drastically by the year 2000 as a consequence of the Clean Water Act. They believed that water conservation and internal recycling would combine to hold demands in the year 2000 at about 90% of the 1975 level. The 1980 data were close enough to the 1975 data that one could not be certain whether the rate of increase in demand had begun to decline or if the 1980 data were but a momentary pause in the rate of increase. The 1985 data provide conclusive evidence that demand was strongly affected by legislation and regulations of the 1970s—in fact, there was about a decade's lag between changing national policy and the effects of the policy change becoming apparent. Because structural changes in waste treatment and water conservation required planning, design, and securing of funding after regulations were written and before construction could begin, a 10-year lag between the law's passage and the first clear evidence of changes in water use is reasonable.

Semi-logarithmic and logarithmic curve forms provided a better fit to the historical data than linear trends. The curves imply that conservation and recycling will continue to occur at levels mandated by 1970s legislation. Additional increments of waste treatment and

Table 9.—Total freshwater consumption (million gallons per day) in the United States for 1960 to 1985, by geographic area and use, with projections of consumption to 2040

Water use	1960	1965	1970	1975	1980	1985	Projections 2000	2010	2020	2030	2040
North											
Domestic self-supplies	427	517	513	356	594	595	482	494	504	511	515
Industrial self-supplies	1045	1351	1187	1177	1247	1656	2790	3155	3523	3891	4262
Irrigation	233	398	460	613	1278	1187	1417	1481	1543	1592	1637
Livestock watering	603	628	614	689	623	650	643	680	711	733	746
Municipal central supplies	1329	1735	1881	1749	1615	1618	2335	2575	2783	2931	3016
Thermoelectric steam cooling	53	87	106	630	1294	2865	5457	6539	7379	8483	9829
Total North	3691	4717	4762	5215	6651	8571	13124	14924	16443	18142	20005
South											
Domestic self-supplies	519	798	721	661	842	843	732	750	766	777	783
Industrial self-supplies	1524	1581	2220	2075	2781	1702	2378	2690	3003	3317	3633
Irrigation	9143	14913	12646	17564	16356	14701	17550	18349	19116	19717	20278
Livestock watering	416	472	540	680	769	992	925	977	1022	1054	1073
Municipal central supplies	1139	1301	1612	2323	2172	2176	3140	3464	3742	3942	4056
Thermoelectric steam cooling	96	228	568	1061	1536	1089	1739	2083	2351	2703	3132
Total South	12837	19294	18307	24364	24455	21503	26464	28312	29999	31509	32954
Rocky Mountains											
Domestic self-supplies	120	136	161	188	293	293	211	216	221	224	226
Industrial self-supplies	157	248	378	601	625	376	503	569	635	701	768
Irrigation	24073	30491	34755	34999	36242	31689	37836	39558	41212	42508	43717
Livestock watering	315	439	476	498	430	524	533	563	589	607	618
Municipal central supplies	495	584	756	857	1303	1305	1883	2077	2244	2364	2432
Thermoelectric steam cooling	48	83	126	207	369	303	482	578	652	750	869
Total Rocky Mountains	25208	31981	36651	37350	39260	34494	41449	43561	45553	47154	48631
Pacific Coast											
Domestic self-supplies	151	117	261	244	253	253	249	255	261	264	267
Industrial self-supplies	249	181	306	332	364	409	1044	1180	1318	1456	1594
Irrigation	18576	20095	25608	26745	29243	26211	30695	32091	33433	34484	35465
Livestock watering	103	82	82	84	80	207	211	223	233	240	244
Municipal central supplies	508	1517	1675	1737	2006	2010	2901	3199	3457	3641	3746
Thermoelectric steam cooling	27	18	24	40	42	96	86	103	117	134	155
Total Pacific Coast	19614	22010	27957	29182	31987	29186	35185	37052	38817	40220	41472
U.S. Total Consumption	61350	78002	87677	96111	102353	93755	116222	123850	130812	137025	143062

Source: Data for 1960 through 1985 from U.S. Geological Survey Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

recycling beyond that mandated by existing legislation are not assumed to occur in the future. Comparisons of projections in 2040 between linear and the two curve forms showed that, on average, demands are 15% to 20% lower for the curve forms than the linear form. The analyses suggest that is a reasonable expected gain from conservation and recycling.

The 1987 release of BMDP Statistical Software (Dixon et al. 1985) for personal computers was used to analyze data and perform projections. Standard BMDP diagnostics were used to evaluate statistical fit and significance. Projection equations and goodness-of-fit statistics are listed in Appendix B. The data consisted of historical water withdrawal and consumption information from USGS reports and demographic information forming the basic assumptions for this Assessment (table 11).

Projections were made by water use category at the national level. The projections were then disaggregated to water resource regions and Forest Service Regions based on the shares each region had of the 1985 total withdrawals and consumption. Where historical data suggested that regional shares were changing, a continuation of the rate of change was factored into the disaggregation process. Results are displayed in tables 8–10 and in Appendix A.

THERMOELECTRIC STEAM COOLING

Thermoelectric power is electricity generated using either fossil-fuel (coal, oil, or natural gas), renewable (wood or geothermal), or nuclear energy. No matter what the energy source, the principal method of generating electricity is to convert water into steam and then use steam pressure to propel the generator's turbine. Spent steam recondenses into hot water which must then be dealt with in some way. In nuclear reactors, the steam generation and recondensation process is typically a closed-loop process where the recondensed water is recycled back to the boiler. Cooling water is used to assist the recondensation process.

Table 10.—Total freshwater withdrawals (million gallons per day) in the United States from 1960 to 1985, by geographic area and water source, with projections of demand to 2040

Region and water source	1960	1965	1970	1975	1980	1985	Projections 2000	2010	2020	2030	2040
North											
Groundwater	5625	7130	8750	8920	9930	9395	12060	13840	15670	17225	18365
Surface water	70735	92000	107355	106975	110050	97785	117110	130450	143600	156350	168450
Wastewater	80	125	130	155	190	105	250	310	325	375	415
Total North	76440	99255	116235	116050	120170	107285	129420	144600	159595	173950	187230
South											
Groundwater	15570	21820	19165	23650	24040	24520	25795	28280	30790	32830	34390
Surface water	34635	42765	57415	68265	83295	70460	82360	91450	100400	109050	117300
Wastewater	30	5	20	65	70	175	100	110	100	105	105
Total South	50235	64590	76600	91980	107405	95155	108255	119840	131290	141985	151795
Rocky Mountains											
Groundwater	12690	15920	18675	27920	31140	29190	27515	29220	30890	32125	33120
Surface water	36420	47420	52740	53380	59745	57520	61475	66320	71075	75100	78850
Wastewater	90	125	170	155	35	55	70	75	65	60	60
Total Rocky Mountains	49200	63465	71585	81454	90920	86765	89060	95615	102030	107285	112030
Pacific Coast											
Groundwater	13400	15930	21130	22430	24150	20790	22430	24560	26720	28410	29625
Surface water	27545	28975	32510	34410	36260	33450	35815	38700	41525	43880	46000
Wastewater	430	385	200	170	175	260	165	165	135	130	120
Total Pacific Coast	41375	45290	53840	57010	60585	54500	58410	63425	68380	72420	75745
Total groundwater	46285	60800	67720	82920	89260	83800	87800	95900	104070	110590	115500
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Total wastewater	630	640	520	540	470	600	590	660	620	670	700
U.S. Total Withdrawals	216200	272400	318300	346600	379000	343700	385200	423600	461300	494800	526600

NOTE—The sum of totals by region and by water source differ because of independent rounding of intermediate sums.

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Table 11.—Data used to project withdrawals and consumption

Variable	1955	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Population[1]	165.9	180.7	194.3	205.1	216.0	227.8	239.3	274.9	294.3	312.1	325.5	333.4
Civilian labor force[2]	65.02	69.63	74.45	82.77	93.77	106.94	115.46	142.54	159.16	175.09	192.26	211.86
Disposable income[3]	5.71	6.06	7.03	8.13	8.94	9.72	10.62	13.92	16.73	19.66	23.53	28.79
Gross national product[4]	1,494.9	1,665.3	2,087.6	2,416.2	2,695.0	3,187.1	3,607.5	5,402.0	7,031.3	9,166.1	11,956.7	15,626.0
Billion kWh generated[5]	-----	557.	791.	1,143.	1,318.	1,612.	1,794.	2,311.	2,765.	3,285.	3,760.	4,265.
Imported oil price[6]	-----	7.67	7.35	7.05	23.49	39.54	24.21	32.08	51.10	69.85	88.86	107.88
Electricity price[7]	-----	16.10	14.20	12.50	15.00	17.50	18.00	19.00	19.50	20.00	20.50	21.00

Notes:

[1]*Million people*

[2]*Million people*

[3]*Thousand 1982 constant dollars per capita*

[4]*Billion 1982 constant dollars*

[5]*Generation by fossil-fueled powerplants. Historical information from Energy Information Administration, projections based upon the historical linkage between GNP and electricity demand described in Department of Energy documents.*

[6]*Constant 1982 dollars per barrel, F.O.B. domestic refinery.*

[7]*Constant 1984 dollars per million BTUs*

Source: Darr (1989)

In fossil-fuel and geothermal power plants, the process is not always a closed loop. "Once-through" cooling was the norm until the early 1970s. Legislation then recognized that putting excess heat back into the aquatic environment was as damaging as putting excess nutrients or allowing suspended sediments into the streams. Excess heat is called *thermal pollution*. Today, power generation facilities use a variety of ways to get rid of waste heat to the atmosphere before piping cooled water back to the stream. Some plants use cooling towers or cooling ponds, relying upon evaporation to cool the water. These are often effective enough that the cooled water can be recycled through the plant. As recycling increases, the amount of water consumed through evaporation will increase.

Electricity generation in the United States has set a new record every year since the early 1940s except for 1982. In 1985, a new record of 2.47 trillion kiloWatt-hours (kWh) was set. Electricity generation from petroleum, natural gas, and hydroelectric power has continued to decline, while generation using coal, nuclear, and renewable resources has continued to rise (fig. 12) (Energy Information Administration 1986a). These changes continue the shifts in mix of fossil fuels that have been underway since the 1950s. The share of electricity generated by natural gas and petroleum has fallen from 37% in 1972 to only 16% in 1985. Generation using petroleum products peaked at 365 billion kWh in 1978 and declined to 100 billion kWh in 1985. Generation using natural gas peaked at 376 billion kWh in 1973 and has dropped to 292 billion kWh since then. The share generated by coal and nuclear fuel has risen over the same period from 47% to 72%. Generation using coal has increased more than 100% since 1970 and stood at 1,401 billion kWh in 1985. Nuclear power generated 384 billion kWh in 1985, a 1000% increase since 1971. The share of electricity generated by hydropower is also on the decline. Although outputs have remained essentially constant, subject to vagaries of the weather, the share has fallen because total generation increased. Hydroelectric power peaked at 332 billion kWh in 1982 but dry weather in recent years resulted in a decline to 282 billion kWh in 1985.

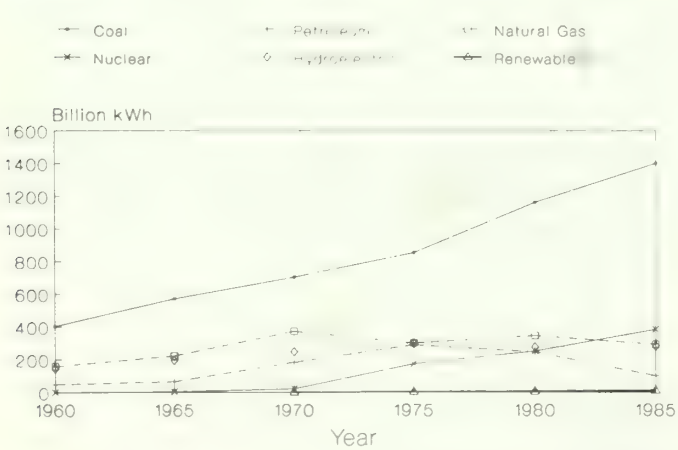

Figure 12.—Electricity net generation by fuel source, 1960-1985 (Energy Information Administration 1986a).

Choice of fuels varies across regions due to availability and transportation costs. The Northeast relies primarily upon nuclear and oil-fired units; the Pacific Coast on natural gas and hydropower. All other regions—especially those in the South and Southwest experiencing the largest rates of population and industrial growth—depend primarily on coal (Energy Information Administration 1986b).

A recent examination of electricity demand between 1953 and 1983 determined that a structural change did occur in 1973 following the Arab oil embargo (Energy Information Administration 1985). A more recent study (Cornett 1985) analyzed changes in demand in the early 1980s following the structural change. This analysis demonstrated that changes in demand were uneven across sectors of the economy and areas of the country. Less rapid growth in electricity use in the residential and commercial sectors can be explained mainly by conservation measures in response to higher electricity prices. Average growth of about 2.0% per year in residential electricity demand between 1980 and 1984 compares with average annual GNP growth of 2.7% for the same period. Average growth in commercial demand exceeded 4%. Industrial growth in electricity demand was down sharply during the last recession. Average annual growth in demand was only 0.8% per year—less than one-third the growth rate in GNP. If growth in residential and commercial demand for electricity remains moderate (as a result of slow growth in housing and commercial sectors) and growth in industrial output remains low, then the ratio of electricity-to-GNP growth rates could remain below 1.0—barely one-half the 1.8 average ratio for the 1953–1984 period. Cornett (1985) found that most of the change in residential and commercial demand for electricity in the early 1980s can be attributed to changes in real income. The change in industrial demand for electricity is attributed largely to changes in output associated with the recession. Cornett concluded that if recent sluggish output trends in housing construction, food, paper, chemicals, and primary metals sectors (the five biggest industrial users of electricity) continue, and if gains in energy efficiency continue because prices remain high, future electricity/GNP growth ratios will continue to remain below 1.0.

Cornett's outlook for electricity demand was amplified in the National Energy Policy Plan (Department of Energy 1985). Energy productivity (GNP per unit of energy consumed) rose 28% between 1974 and 1985—14% between 1981 and 1985, the greatest improvement in efficiency since World War II. This progress is continuing for all types of energy including electricity. Energy conservation has made a bigger contribution to reducing the need for new or imported energy resources than any change in fuels has accomplished (e.g. substituting coal for petroleum). The plan proclaimed coal as the fuel for America's future. It has become the main fuel for electric utilities. Modern coal-fired powerplants are cleaner than most older oil-fired plants. New technologies to burn coal are being developed that promise even higher efficiencies and environmental performance. The increased demand for coal will lead to

more mining which has implications for mine-related water impacts.

Nuclear energy is now the second-largest source of electricity and provides 15% of the nation's needs. This is expected to rise to 20% by the turn of the century. Renewable energy resources (now primarily wood and water) contribute about 9% of the country's domestic energy production. This could rise to nearly 13% by the end of the century and to 15% by 2010 as more economical renewable energy technologies (e.g. wood, geothermal, solar, or wind) develop.

Future trends in energy consumption, particularly electricity consumption, suggest that efficiency increases will continue. The National Energy Policy Plan projects that it could take 20 to 30 years to gain full advantage of all the opportunities for efficiency that have been recognized in the industrial sector. The residential sector has shown a 40% drop in energy use per household since 1973 due largely to improved insulation, improved appliance efficiency, and changes in household behavior. Further, the average efficiency increase in energy-using capital goods will increase over time by an additional 20% to 50% through normal turnover of stock and implementation of more efficient technologies.

Given the assumptions of energy conservation outlined above, the nation will need between 100 and 300 gigawatts of new electrical generation capacity between now and the year 2000; over and above the 70 gigawatts under construction in late 1985. This new capacity will be needed to replace obsolete units as well as satisfy growth in electricity demand. The nation currently has some excess electrical generation capacity. Utilities are trying to stretch their capacity by improving operation and maintenance. They hope to boost utilization factors of generating units by 10% to 25%. More intensive use of existing capital will help postpone new construction but does not significantly reduce cooling water needs.

Another way of meeting power demands is to import energy. Power imports from Canada (principally hydropower) have grown six-fold since 1970. They are expected to double from the current 40 billion kWh level (2% of domestic demand) to 80 billion kWh by the year 2000 (3% of domestic demand). Between excess capacity and improving utilization, conservation, interconnection of power distribution networks, and imports from Canada, public utilities are attempting to stave off the need for construction of new powerplants.[2] However, by the turn of the century, significant expansions in construction programs of many utilities will inevitably occur to meet rising demand.

Current projections by the Department of Energy show demand for electricity growing in rough proportion to growth in the nation's economy for the foreseeable future. The question pertinent to this Assessment is the nature of the relationship because cooling water withdrawals are made in direct proportion to the number of kWh generated by fossil-fuel, nuclear, and wood-burning powerplants. All conclusions by the Department of Energy (1985) suggest that the historic tie between rate of growth in GNP and electricity demand has undergone a major structural change since the mid-1970s and that the ratio of growth in electricity generated to growth in GNP is likely to stay below 1.0 well into the next century. Efficiency gains reported and expected mean that the nation will use less electricity to produce increments of GNP in the future than in 1950s and 1960s. Consequently, this Assessment adopts the 0.8 ratio determined by the Department of Energy for the early 1980s and projects kWh as a linear function of the growth in GNP.

Water use and trends.—Thermoelectric powerplants furnish practically all of their own water; less than 1% is obtained from public supplies. In 1985, total water withdrawals for thermoelectric steam cooling totaled 187 bgd—a decrease of 11% from 1980. This total includes 130.4 bgd of freshwater and 56 bgd of saline water (saline water withdrawals and consumption are not studied in this Assessment). The 1985 freshwater withdrawal level is 12% less than the 1980 level and the same as withdrawals in 1975 even though the kWh generated have increased 36% since then (figs. 13–16; tables A.1, A.7, and A.13; figs. A.3 and A.4).

About 99% of withdrawals are used for condenser and reactor cooling of generators. About 4% of freshwater withdrawn is consumed, up from 2% in 1980, 1% in 1975 and 0.5% in 1970.

Thermoelectric steam cooling is the second largest withdrawal use next to irrigation. It has been the fastest growing use in recent years. Assumptions made about the continued increase in demand for electricity lead to projections of withdrawals that make it the largest use of water by 2040. Most of the increase in water use comes after 2000 when a large number of new power plants begin generation.

One of the largest withdrawal uses—thermoelectric steam cooling—is one of the smallest consumptive uses. Consumption has been rising rapidly, but from an extremely small base. Consumption is projected to double by 2010 and triple by 2040. However, even by 2040, consumption is still projected to be only 6% of withdrawals.

Potential for changes in the projections.—Because electrical demands are tied so closely to GNP increases, and because GNP growth rates show long-term increases, it would take a major economic disturbance to significantly alter these long-run withdrawal and consumption projections. The Arab oil embargo of the early 1970s was just such a disturbance and resulted in a structural change in the electricity/GNP long-term trend. Other potential events that could significantly alter withdrawals and consumption include additional major water quality legislation directed at thermal pollution, which would boost consumption and cut withdrawals, and the advent of practical uses for recently invented superconductor materials, which would reduce withdrawals.

IRRIGATION

Irrigation is the act of applying water to land to promote vegetation growth or obtain other benefits. In arid and semi-arid parts of the Rocky Mountains and Pacific Coast, irrigation is needed to raise most non-native

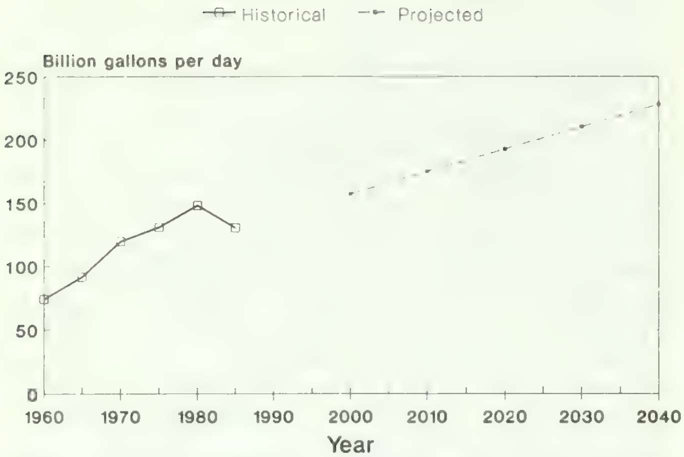

Figure 13.—Thermoelectric stream cooling, total freshwater withdrawals.

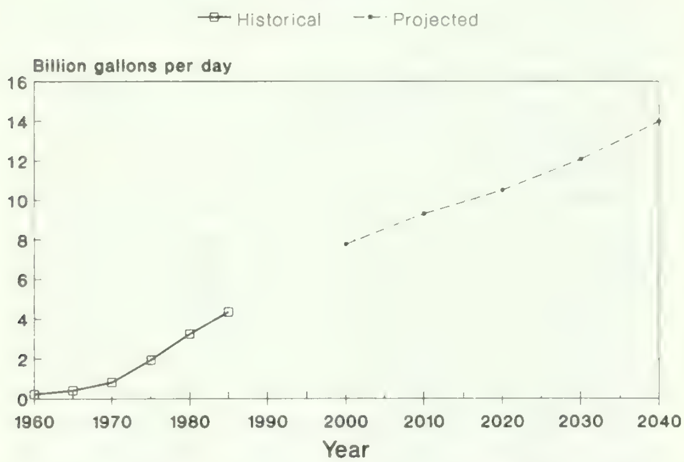

Figure 14.—Thermoelectric steam cooling, total freshwater consumption.

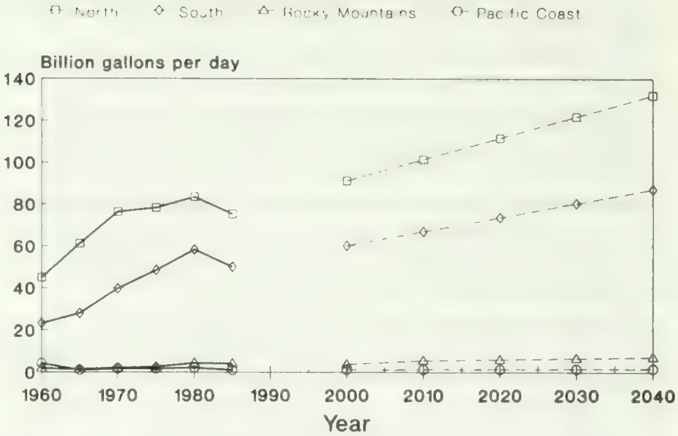

Figure 15.—Thermoelectric steam cooling, freshwater withdrawals by region.

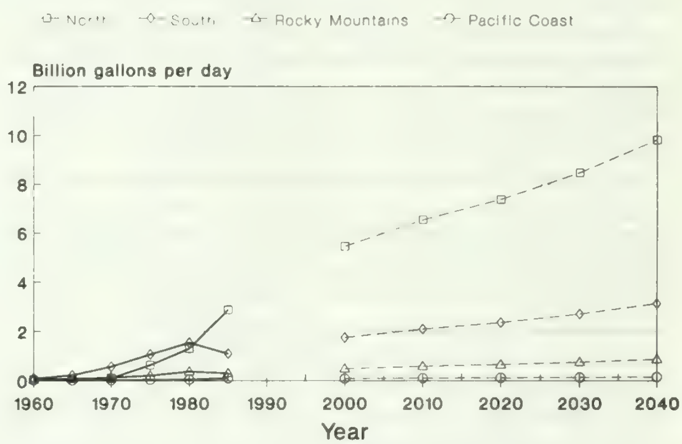

Figure 16.—Thermoelectric steam cooling, freshwater consumption by region.

vegetation. Agricultural, horticultural, and viticultural activities depend on regular applications of water at frequent intervals. In many Western areas, home, business, roadside, and recreation settings, turf and landscape plantings require irrigation too. Irrigation also promotes beautification in residential and business settings and helps keep buildings cooler.

Irrigation is often essential to recreation activities such as managing turf on golf courses and making snow for downhill skiing. In rural areas, irrigation of roadside plantings and property perimeters can assist in wildfire control by establishing a buffer of less-combustible vegetation. In the more humid North and South, irrigation also provides an increase in the number of plantings per year, yield per crop, and reduces the risk of losses during drought periods. High-valued crops such as fruits and vegetables are irrigated to maintain quality standards and some canners and processors will not buy non-irrigated produce. Irrigation is also used to reduce nursery and fruit losses to late spring and early fall frosts. Estimates of withdrawals and consumption of water for irrigation purposes vary greatly because of the many factors involved.

Most irrigation involves crops. If acres in crop production and water application rates can be determined, then some reliable estimates of withdrawals for irrigation can be made. Additional information about evapotranspiration must be known to reliably estimate consumption. This data is scarce. Different sources of irrigation information gather data in different ways, thus complicating the process of estimating acreage irrigated. For example, the Census of Agriculture conducted by the Department of Commerce reports land as irrigated only if irrigated in the year of the census. The Natural Resources Inventory conducted by the SCS every 5 years records land as irrigated if irrigated in the year of the survey or in two or more of the preceding four years. Irrigation trade associations publish statistics based upon other criteria. An extensive analysis of irrigation water requirements for croplands was conducted by Flickinger (1987) for the Appraisal.

Day and Horner (1987) present data on the history of irrigated agriculture. In 1889, 3.6 million acres (0.6%) of the 623 million acres of farmland in the U.S. were irrigated. All irrigated land was located in the arid and semi-arid West, principally California (1 million acres) and Colorado (0.9 million acres). In 1889, 54,000 farms were irrigating an average of 67 acres and each producing $11.50 per acre in crop value. Today, about 45 million acres of farmland are irrigated, an average of 210 acres

per farm and producing about $530 per acre. Irrigated land area has grown continuously, except for several years during the Great Depression and during 1978–1984. The growth rate declined since the mid-1950s except for a brief increase from 1969 to 1978. The proportion of irrigated to non-irrigated farmland reached a record high of 5% in 1978 with approximately 50 million acres irrigated. Since then, irrigated acreage of farmland declined by about 11%. During the recession of 1982–1984, irrigated acreage declined 4.3 million acres.

A major factor behind the rapid expansion of western irrigation during 1880 to 1900 was the need for winter feed to sustain the growing cattle industry. Simple low-head dams and stream diversion structures were constructed to flood meadows and irrigate hay and other feed crops. Without winter feed, it is likely that millions of acres of rangeland would have been underused and the feed grain-livestock economy of the Great Plains might never have developed. Today, 60% of irrigated farmland is used to produce forage, roughage, and feed grain crops (corn, barley, oats, sorghum, hay, pasture, and silage) for livestock.

Wheat and rice production—food grains for humans—slowly gained importance as a component of irrigated farmland, rising from a 10% share in 1889 to a 17% share by 1982. As agricultural technology and transportation systems improved and as consumer demand for a wider variety of crops increased, irrigated land increasingly was devoted to what were initially known as "specialty crops". Today, this list includes cotton, sugarcane, peanuts, tobacco, soybeans, vegetables, and orchards. Twenty percent of farmland irrigated is used to grow these crops (Day and Horner 1987).

Day and Horner (1987) document how irrigation use differs among regions. The Pacific Coast and Rocky Mountain regions account for 85% of irrigated farmland in the U.S. About 12% of southern farmland is irrigated, principally the river delta areas in Arkansas, Louisiana, and Mississippi, where rice, cotton, and sugarcane are grown extensively, and in Florida where citrus and vegetables are widely grown. The rapid growth of irrigated farmland in the South is largely due to expansion in Georgia, now the eighth largest state for irrigated corn production (Bajwa et al. 1987). Irrigation is much less prevalent in the North, but supplemental irrigation is expanding rapidly in the Lake States and Corn Belt (Iowa, Missouri, Illinois, Indiana, and Ohio) as farmers learn how to augment rainfall to improve planting schedules and reduce weather risks. About 4% of the farmland in the North is irrigated.

The federal government played a large role in the development of irrigation in the western states. The Reclamation Act of 1902 established the Bureau of Reclamation in the Department of the Interior to facilitate settlement of the western States by developing irrigation water supplies. Since then, the Bureau has carried out an extensive program of dam and water distribution system construction and operation. In 1982, 10.9 million acres of land were irrigated with water from Bureau of Reclamation projects. This acreage produced about $7.3 billion in gross revenues. These figures represented about 20% of all irrigated farmland in the contiguous U.S. and about 30% of the value of all irrigated farmland outputs (Day and Horner 1987).

U.S. farmers use two basic types of irrigation water application systems—gravity and sprinkler. Gravity systems apply water using gated pipes, ditches with siphon tubes, overland flooding, and underground porous pipes (subirrigation). Gravity systems were used on 27.5 million acres of farmland in 1984 (Day and Horner 1987). Bajwa et al. (1987) reported that the farmland acreage irrigated by gravity systems dropped 12% between 1979 and 1984.

Sprinkler systems are the more modern of the two application systems and also more expensive. Sprinklers include different types of equipment delivering water under pressure. Hardware includes center pivot systems, side-roll units moved either mechanically or by hand, permanent sprinklers, moveable and permanently mounted guns, and drip systems. Sprinkler systems were used on 18.3 million acres of farmland in 1984 (Day and Horner 1987). Bajwa et al. (1987) reported that farmland acreage irrigated with sprinklers dropped 8% between 1979 and 1984.

A relatively new pressurized method currently included in the sprinkler figures is drip or trickle irrigation. This technique is very popular in orchards. Its use expanded by 161% between 1979 and 1984, but the total acreage irrigated with this method in 1984 was still less than 1 million acres. The major virtue of drip or trickle systems is less water use than conventional sprinkler systems. Major disadvantages of drip systems are they cannot be used to flush salts from saline soils and they are expensive.

Water use and trends.—Irrigation water withdrawals in 1985 totaled 142.5 bgd, a decline of 6% since 1980 (fig. 17). The 1985 level of withdrawals is equivalent to the 1975 level. Irrigation withdrawals in 1985 were larger than for any category of water use. Irrigation is by far the largest consumptive user. Consumption totaled 73.8 bgd in 1985, or 78% of the total consumption by all uses (fig. 18). It is this aspect of irrigation water use that has the most significance for current and projected future water use and development. Regional breakdowns of irrigation water withdrawals and consumption are shown in figures 19 and 20 and tables A.2, A.8, and A.14; and by source in figures A.5–A.7.

Irrigation water comes from wells, on-site surface sources, and surface sources provided by off-site suppliers such as irrigation districts and ditch companies. The principal source is from wells—56.3 bgd, or 68% of total groundwater withdrawals. Surface withdrawals amounted to 85.8 bgd in 1985, which is 33% of total national withdrawals. Bajwa et al. (1987) report that 3 of every 4 gallons from surface sources are provided by off-site suppliers. As discussed in Chapter 2, irrigators in the Great Plains rely heavily on groundwater withdrawals while irrigators in other parts of the Rocky Mountain and Pacific Coast regions rely heavily on off-farm suppliers.

Because both wells and on-farm surface water sources must be pumped to deliver water to crops, energy expenses of irrigating farmland can be quite high. Total energy expenses for irrigation pumping reached $1 billion in 1984. Average expenditures per acre grew by 60% from $20 per acre in 1979 to $32 per acre in 1984. This growth in energy costs occurred during the same period that farmland acreage irrigated fell by 11%. Viewed in this context, the rise in energy costs is even more dramatic. Five sources of energy are used to pump irrigation water—electricity, natural gas, liquid propane (LP) gas, diesel oil, and gasoline. Electricity dominates at 58%, natural gas is 19%, and diesel oil 17% of the irrigation pumping energy market. Since 1979, electricity usage grew in importance, natural gas declined, and diesel oil held steady (Bajwa et al. 1987).

Flickinger (1987) reported that water withdrawals by farmers for irrigating crops in 1982 was 129.6 bgd—about 87% of total irrigation withdrawals for that year. The fundamental difference between Flickinger and USGS estimates is that Flickinger carefully estimated withdrawals and consumption *only* for agricultural uses. USGS estimates include withdrawals for non-agricultural uses. In some water resource regions, Flickinger's estimates were larger than the 1982 estimate interpolated from USGS numbers. This Assessment concurs with Flickinger's estimates for agriculture and uses them as a base. In water resource regions where USGS estimates are larger than Flickinger's, USGS numbers are used to account for non-agricultural irrigation. The pattern of water resource regions where USGS estimates were higher fit the expectation of regions having significant non-agricultural irrigation. Thus, irrigation withdrawals and consumption numbers in this Assessment are somewhat larger than the irrigation estimates for 1985 by Solley et al. (1988).

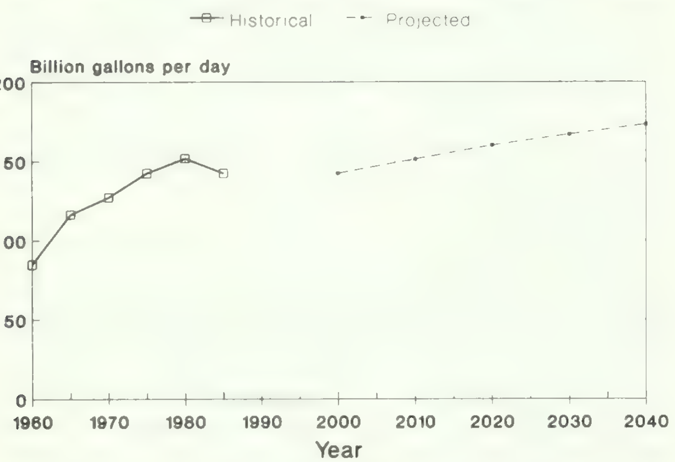

Figure 17.—Irrigation, total freshwater withdrawals.

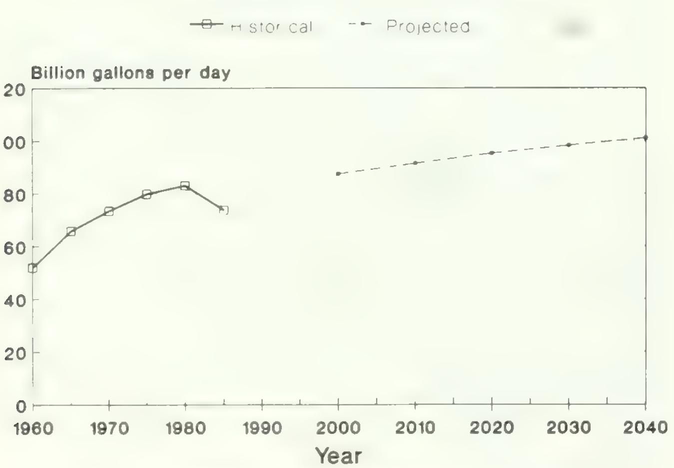

Figure 18.—Irrigation, total freshwater consumption.

Bajwa et al. (1987) contains detailed information on the farmland irrigation situation in each state including methods, sources, and expenses of irrigation and comparisons of the average value of farm capital for farms using irrigation compared to dryland production practices.

Potential for changes in the projections.—Irrigation water usage is projected to grow at a much slower rate over the next 50 years than over the previous 25 years. From 1960 to 1985, the average annual growth increase was 2.1%. From 2000 to 2040, the projected growth rate is 0.5%. A major reason is the continuing increase in pumping costs. Energy cost increases and aquifer declines increase pumping costs. Increased pumping costs reduce net return per acre, thus narrowing the advantage enjoyed by irrigated crop production over dryland crop production. The point has been reached in parts of the Southern Great Plains where net returns from irrigated crop production are lower than for dryland crop production. As soon as irrigation equipment is depreciated and paid for, many farmers stop irrigating. If crop prices rise, additional income may restore the cost advantage of using irrigation.

Bureau of Reclamation water pricing policies have come under scrutiny recently by interests seeking to reduce crop production subsidies. Irrigators are charged for water obtained from Bureau projects, but prices are user-favorable. If prices increase, then irrigation water use is expected to decline below projected levels. Also, a shift from irrigating low-valued crops such as alfalfa, hay, and pasturage would likely occur.

Technological advances in irrigation are expected to continue because of expected cost increases in pumping water. Chief among new technologies to be implemented soon are drip and trickle irrigation systems. These enable the farmer to control water applications much more precisely and have much lower losses to evaporation and excess runoff. It has been shown that evaporation loss from sprinklers is an exponential function of wind velocity and that in the southern plains, an average of 17% of the water passing through a standard sprinkler nozzle evaporates before reaching the target (Clark and Finley 1975). Other management practices could be employed to reduce energy and related irrigation costs (Gilley 1983). To the extent that such practices are adopted, projected withdrawal and consumption projections could reflect even less than a 0.5% growth per year, perhaps even an absolute reduction. The recent downturn in use (figs. 17–20) may be the beginning of a downward trend, but the 1990 water use estimates are needed for confirmation.

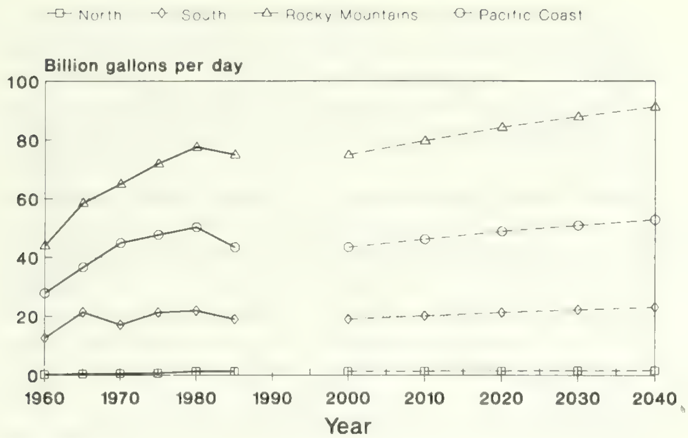

Figure 19.—Irrigation, freshwater withdrawals by region.

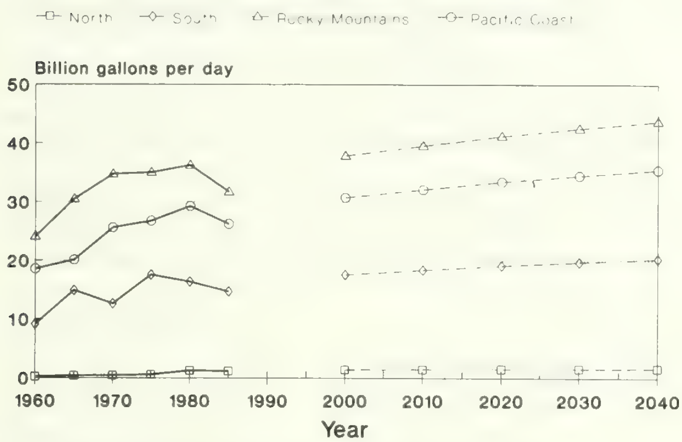

Figure 20.—Irrigation, freshwater consumption by region.

MUNICIPAL CENTRAL SUPPLIES

Municipal central supplies refers to water withdrawn by public or private water supply utilities who distribute treated water through a network of pipes to household, commercial, and industrial users. This use category contrasts with domestic and industrial self-supplied use—those entities each withdraw water for their own needs from surface or groundwater sources. Municipalities may contract with a private firm to supply water or have their own supply and treatment systems.

Municipal systems serve a variety of users. Foremost are individual households; however, commercial establishments—stores, restaurants, and light industry—are also usually served by municipal supplies. There comes a point for many industries when a corporate decision must be made whether or not to rely on municipal supplies for their entire water needs. Such a decision is fundamentally one of cost. A firm may use water in their manufacturing process as a major component of the product as in brewing beer, or as an adjunct such as cooling in steel mills. In the former case, the quantity required by a new facility is so large that it could overwhelm the municipal supplier's ability to provide it. In this case, it is often less expensive for the firm to develop its own supply. In the latter case, water of a lower-than-potable quality is needed, so paying a municipal supplier to treat the water to potable levels is more costly than developing an independent supply. Finally, if high costs are associated with production process interruptions due to water shortages, then an auxiliary private supply may be developed as a safeguard against interruptions.

In addition to providing water for household, commercial, and some industrial uses, municipal central-supplies also include water for public uses. Public uses include fire protection, street washing, municipal parks, and swimming pools.

Water use and trends.—The total water withdrawals for municipal supplies reached 36.5 bgd in 1985, an increase of 7% over 1980. The trend in municipal withdrawals is one of steady increases over the past 25 years (table 8 and fig. 21). Consumption, on the other hand, has remained constant since 1980 at 7.1 bgd (table 9 and fig. 22). Regional withdrawal and consumption patterns are shown in figures 23–24.

Historically, larger cities used surface water as the municipal source while smaller towns used groundwater. Between 1980 and 1985, there was an increase in groundwater withdrawn and a decline in surface water withdrawn (figs. A.8–A.9). This pattern supports the observed trends in population migration from cities to rural settings. The percentage of the population served by municipal systems increased 2% since 1980 to 83% in 1985. This percentage may be near the upper limit that can be reasonably served by central systems given costs of extending water mains into rural areas having low population.

Some evidence is emerging from per-capita use rates of municipal supplies that water conservation is occurring. Per-capita household use in 1980 was 120 gallons per day (gpd), 117 gpd in 1975, and 115 gpd in 1970. The 1985 data show per-capita household use at 105 gpd—a significant reduction given the short-term trend. Two factors probably play a large role in this reduction. The first is that municipalities have recently begun major renovations of water supply systems. New technology developed in the last 20 years has given municipalities a clear understanding of the status of leaks in water mains and distribution systems for the first time and also a means of fixing problems without the tremendous cost of excavating and replacement. Excavation and repaving are the most significant costs associated with repairing leaks. Miniature television cameras and new leak detection developed in the 1970s now permit direct observation of the inside of pipes to locate leaking sections without excavation. Pipe sections and joints needing repair can be pinpointed before digging. Techniques have also been developed to reline existing pipes with plastics and polymers to improve leak resistance, again without excavating major sections of water main. Thus, technology makes it much more economical to fix leaks than to add additional water withdrawal and treatment capacity. Because per-capita use is measured by the volume of water entering the distribution system at the treatment plant, repairing leaks reduces per-capita use.

The second major factor affecting per-capita use is household adoption of water conservation measures. A

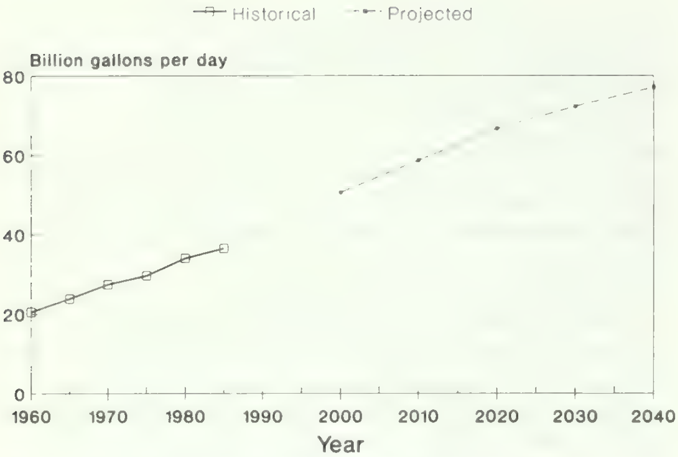

Figure 21.—Municipal supplies, total freshwater withdrawals.

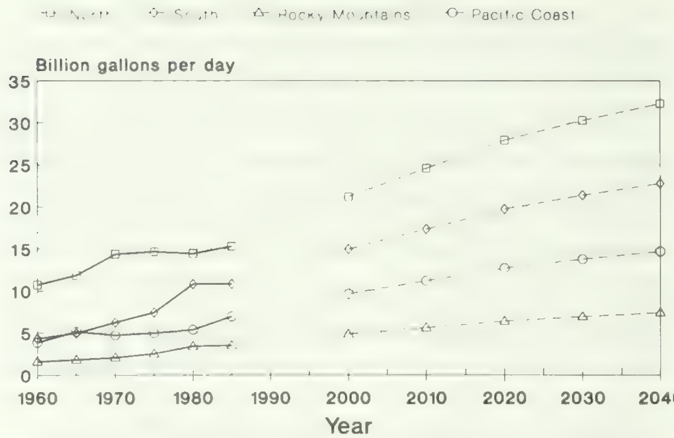

Figure 23.—Municipal supplies, freshwater withdrawals by region.

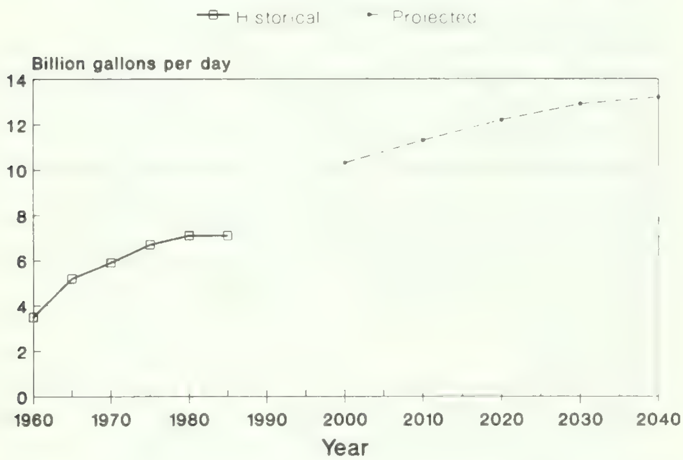

Figure 22.—Municipal supplies, total freshwater consumption.

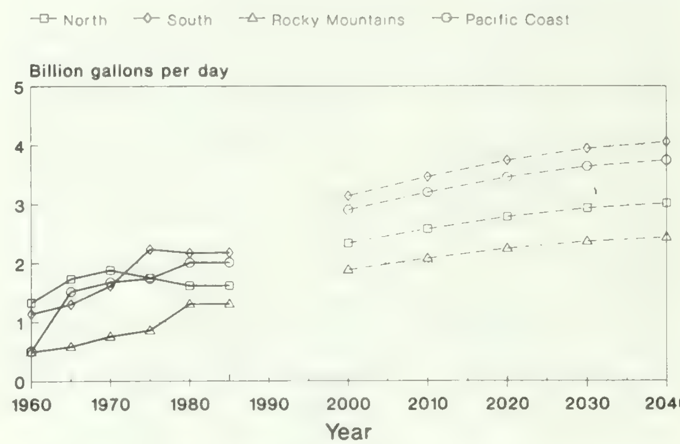

Figure 24.—Municipal supplies, freshwater consumption by region.

variety of improvements have been made in residential plumbing fixtures and home appliances to decrease water use. Showerheads that use less water, water-saver cycles on laundry and dish washers, and commodes that use less water per flush have all been developed since the 1960s. These measures have gradually been adopted in sufficient numbers to reduce per-capita water use. Per-capita use trends also show some regional variation—use in the West is higher than in the East. Lawn watering is likely the key to explaining much of the regional variation.

Potential for changes in the projections.—Over time, water main servicing and water-saving fixtures and appliances will become more heavily used. The extent to which adoption of these items is hastened or delayed will cause the actual municipal withdrawal level to also fluctuate.

INDUSTRIAL SELF-SUPPLIED WATER USE

Self-supplied industrial water use is categorized in this Assessment as water withdrawn and consumed by industries for their own use, except cooling thermoelectric power plants. Major water using industries that have developed their own supplies include steel, chemicals and allied products, paper and allied products, mining, and petroleum refining. Water is used by industries primarily for cooling, washing, conveyance, and as part of the final product. As previously described, the decision to supply one's own water is a corporate one made on the basis of cost-efficiency.

Water quality legislation of the early 1970s imposed more stringent regulation upon industries that were discharging waste into streams. Many firms supply their own water. Water quality regulations required industries to discharge waste streams to municipal systems which were then authorized to charge the industry for treating the wastewater or to build a separate waste treatment facility.

Because many industrial waste flows contain pollutants that are not effectively removed by conventional municipal waste treatment plants, many small- to medium-sized municipalities were reluctant to handle industrial flows. If they decided to accommodate the flow, costs charged the industry were often quite high because special treatment processes had to be installed for the entire municipal plus industrial flow volume. Consequently, constructing a separate industrial waste treatment plant was often the strategy selected. Building such plants was costly. In an effort to reduce capital expenses, much effort was devoted to reducing the volume

of waste needing treatment. Like municipalities, many industries have begun ambitious leak detection and repair programs. Consultants and contractors providing these services flourished. Opportunities to recycle water were also explored in an effort to reduce flow volumes needing treatment.

Water use and trends.—Industrial self-supplied water withdrawals declined 33% between 1980 and 1985 to 26.4 bgd (fig. 25). This level is far below the recent trend in industrial withdrawals; withdrawals have hovered at 39 bgd since 1970 and have been greater than 33 bgd since 1960. Surface water withdrawals dropped 30% since 1980 and groundwater withdrawals dropped 41% (tables 8, A.4, and A.10 and figs. A.10–A.12). Consumption decreased 9% since 1980 to 4.1 bgd (tables 9 and A.15 and fig. 26). Increased recycling is expected to increase consumption. Regional patterns in withdrawal and consumption are shown in figures 27–28.

Projections of industrial self-supplied water use are the weakest of the six categories of uses. Figures 25 and 27 show how the historical trend has fluctuated; these data have no significant association with historical trends in GNP. A major reason is the types of industries that are heavy water users in comparison with industries that have contributed to GNP growth in recent years. Heavy water users have shown mixed performance during the past 10 to 20 years. While paper, chemicals, and allied products show some increases in outputs in recent years, steel, mining, and petroleum refining have not fared as well.

The steel and petroleum industries took a beating in the recession of the early 1980s. Growth in those industries is practically nonexistent. In addition to more stringent water pollution regulations, these industries had to comply with more stringent air pollution regulations. The consequence is that much of the capital normally used for plant expansion or efficiency was diverted to pollution abatement; thus, industries are overburdened with obsolete or inefficient production facilities. These industries are among the most heavily unionized industries remaining in the U.S., which adds another layer of complexity to the process of adjusting to a new production environment.

Potential for changes in the projections.—Because historical trends are not very responsive to basic assumptions used in this Assessment, the potential for projection changes is great. Major industries using self-supplied water have been heavily impacted by the early 1980s recession and the recovery of some is not yet underway. It is impossible to say how much of the

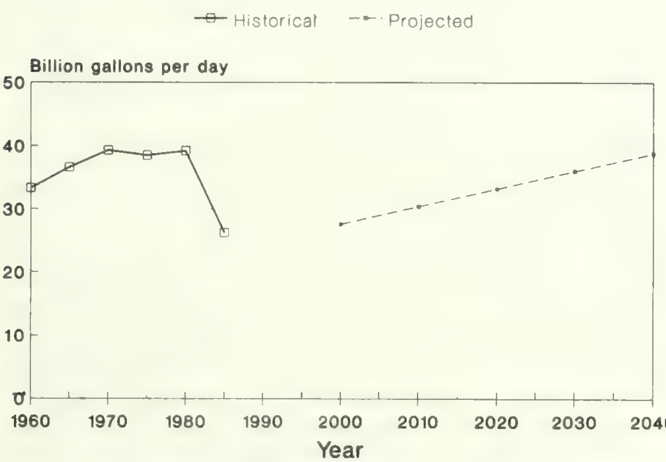

Figure 25.—Industrial self-supplied water, total freshwater withdrawals.

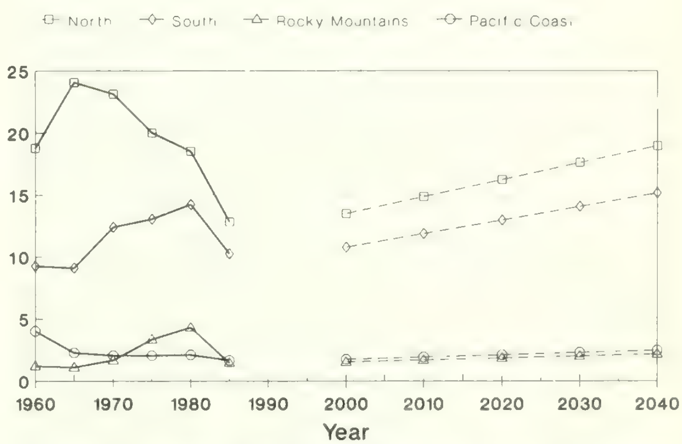

Figure 27.—Industrial self-supplied water, freshwater withdrawals by region.

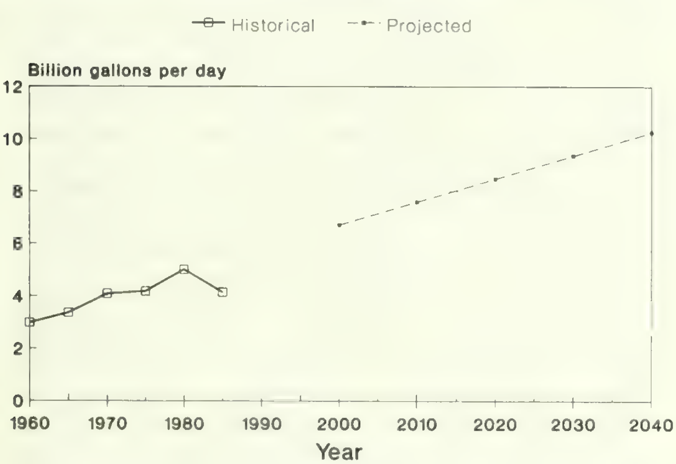

Figure 26.—Industrial self-supplied water, total freshwater consumption.

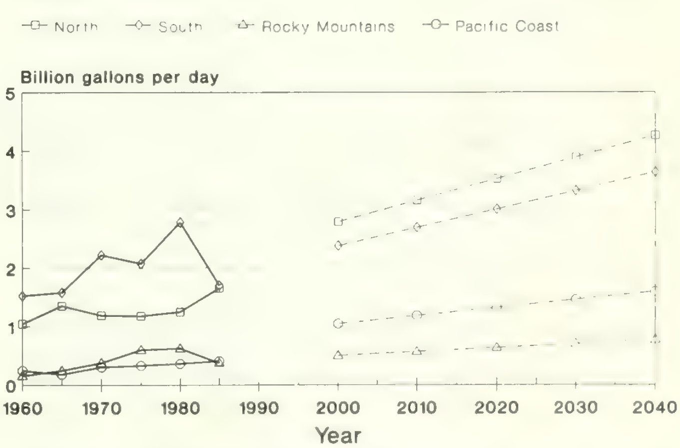

Figure 28.—Industrial self-supplied water, freshwater consumption by region.

reduction in water use is attributable to long-term trends versus short-run industrial economic conditions. Certainly if these industries were all vibrant and had rosy futures, projections of self-supplied water use would show increases over time.

The U.S. economy shifted in recent years from one driven by the engines of basic heavy industry—steel, mining, and railroads—to an economy driven more by "high tech" and service industries—such as computers, electronics, food service, and health care. The U.S. economy emerged from the depths of the Great Depression by the mobilization of the basic heavy industries for World War II. The economy literally fought its way out of the Depression. In the past 20 years, considerable production in these heavy industries moved to other countries, such as steel-making to the Far East. Consequently, our environment is cleaner. The Ohio River no longer flows rust-red south of Pittsburgh, Pennsylvania; West Virginia's rivers are no longer yellow with sulfuric acid from coal mining; and the Cuyahoga River below Akron, Ohio no longer burns in Cleveland's harbor.

But a price has been paid for our cleaner environment not only in terms of expenditures for pollution control, but also in terms of jobs exported and a loss of heavy industry. Ignatius (1988) reported that 245,000 steel workers lost their jobs between 1979 and 1988. In the decade from 1977 to 1986, 24 steel companies disappeared in mergers or bankruptcies. Firms that survived drastically reduced their capacity. USX Corporation, the successor to U.S. Steel, reduced its capacity from 33 million tons per year in mid-1983 to 19 million tons in 1987. Railroads, barge lines, and coal companies—all dependent upon the steel industry—shared in the decline in business and economic activity. One factor contributing to these changes was the capital, operation, and maintenance costs of water and air pollution cleanup and abatement.

A prevailing view of the U.S. economy beyond 1990 is that service industries will continue to grow in importance. Service industries tend to use much less water than heavy industry, largely because cooling and washing requirements are much lower, so volumes of water to be treated will grow at a slower rate than recently.

Waste flows from service industries fall into two categories. The first are flows very similar to household waste generated by industries such as food or financial services. Treating them at municipal plants will cause no unusual problems other than making certain sufficient capacity exists. The second type of waste flow from service industries is very dissimilar from conventional household flows. These flows contain pollutants such as products of biochemical reactions that are more difficult to process in conventional waste treatment plants than the sediments and BOD for which they were designed. Specialized in-plant treatment facilities using advanced methods such as reverse osmosis, activated carbon adsorption, or incineration will be needed to treat these waste flows. The trend towards providing this level of treatment at the waste source will increase.

Industrial self-supplied water use projections in this Assessment are based on a period when industrial production is in a state of flux. Consequently, projections are subject to uncertainty. In the discussion on factors that might influence how projections change, the general conclusion is that the rate of increase in volumes has ceased, unless a major recovery of the heavy water-using industries occurs. A decline in total flow volume for self-supplied industries may have begun; the 1990 USGS data will be needed to confirm that point. Another general conclusion is that the character of the waste flows is also likely to change as service industries emerge as a more prominent sector of the U.S. economy.

DOMESTIC SELF-SUPPLIED WATER USE

Domestic self-supplied use reflects the population not served by municipal central-supplied water systems and occurs primarily in rural areas. USGS estimates the number of people who supply their own water by subtracting number served by central systems from the total U.S. population. The percent of population served by domestic self-supplied water has dropped steadily from 31% in 1955 to 17% in 1985.

Water for rural use includes water for household consumption, drinking water for livestock and other uses such as dairy sanitation, evaporation from stock-watering ponds, cleaning, and waste disposal. Because water for these uses is drawn largely from wells serving individual dwellings or business locations, and because these water supply systems are rarely metered, few "hard" data on rural water use exist. Consequently, information presented in this section and the subsequent one on livestock use represent the best estimates of the USGS on trends in water use in rural areas.

Total rural use is broken into two components—domestic self-supplied use and livestock use. The former includes estimates of household use and use around the home such as vehicle washing and lawn watering. Waste disposal in rural areas is also individualized, primarily through septic systems. The latter category includes estimates of livestock consumption and sanitation such as manure disposal via holding lagoons and pasture irrigation. Livestock use will be discussed further in the next section.

In the 1930s and 1940s, many rural households lacked indoor plumbing. Per-capita water use rates on the order of 10 to 15 gpd were common. Wind, and later electricity, was commonly employed to fill elevated tanks that supplied water by gravity to plumbing. In 1955, about 20% of rural homes had running water, with per-capita use between 50 and 60 gpd. Since then, more and more rural households use electric water pumps to fill pressurized tanks. Installation of modern appliances in rural homes served by pressurized systems increased per-capita consumption to about 80 gpd. (Houses served by municipal central supplies use about 105 gpd per capita.[3]) The difference in per-capita water use is due in part to differences in water pressures between individual and municipal systems. Municipal systems commonly operate at 60 pounds per square inch (psi) of water pressure while individual systems commonly operate between 25 and 40 psi.

Water use and trends.—Total withdrawals for domestic self-supplied water were 3.3 bgd in 1985, a drop of 0.6% from 1980 (fig. 29). Populations served by domestic self-supplied systems remained essentially constant at 40 million people over this time period.

Groundwater is the primary source of water for domestic self-supplied use (figs. A.13–A.14). In 1985, only 1.8% of domestic self-supplied water came from surface sources. This represents a 67% drop from the 5.4% in 1980 that came from surface sources. Consumption from 1980 to 1985 remained constant at 2.0 bgd (fig. 30). Regional patterns are shown in figures 31 and 32.

Total withdrawals for rural domestic uses are projected to increase 76% between 1985 and 2040. New groundwater withdrawals are the source of this increase (tables 8, A.5, and A.11 and figs. A.13–A.14). Consumption is projected to decrease 10% over the same period (tables 9 and A.17 and fig. 30). Increasing withdrawals in the face of decreasing consumption reflects the conversion to pressurized water systems for most rural households by 2040 and the addition of appliances to households.

Potential for changes in the projections.—As water-conserving appliances make broader inroads into rural construction and home remodeling, the rate of increase in water withdrawals will slow. Water-conserving fixtures were discussed under the municipal section above. If installation of these fixtures and appliances proceeds more quickly than recent trends, the rate of increase in withdrawals will be faster than projected.

In all areas of the U.S. except the North, a higher percentage of water supplied to rural households is consumed than is withdrawn. The North has 46.5% of domestic self-supplied withdrawals but only 30% of the consumption. The South has 33.9% of withdrawals and 42.5% of consumption; the Rocky Mountains 9.1% and 14.8%, respectively; and the Pacific Coast 10.5% and 12.7% respectively. Consumption in this context means loss to evapotranspiration or consumption by humans. The rural areas of the North are more densely populated than are rural areas elsewhere, so a larger percentage of withdrawals occur in the North. As rural areas in other parts of the country become more densely settled, withdrawals there will become more prevalent. Population shifts underway from the North to the South and West will result in greater withdrawals and consumption, in absolute terms, in those regions. If the population migration occurs more rapidly and if the "back to nature" out-migration from urban areas increases, projected increases in withdrawals and consumption will be greater.

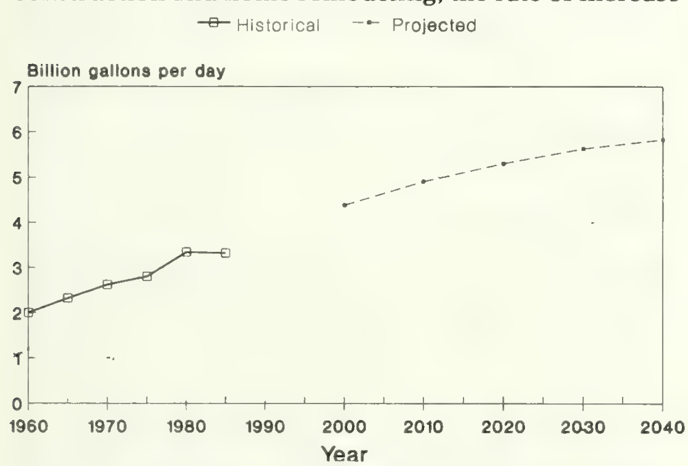

Figure 29.—Domestic self-supplied water, total freshwater withdrawals.

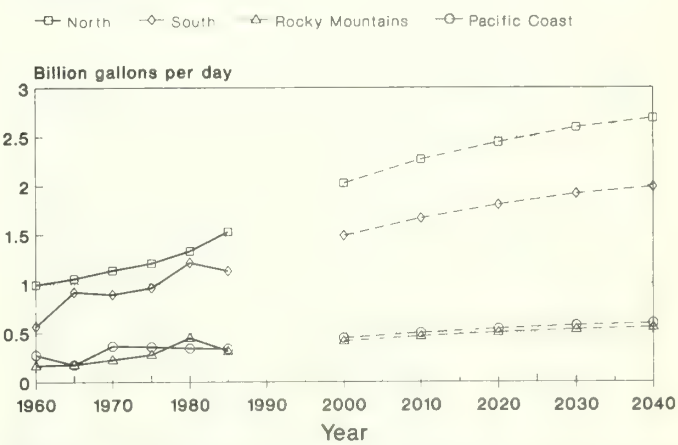

Figure 31.—Domestic self-supplied water, freshwater withdrawals by region.

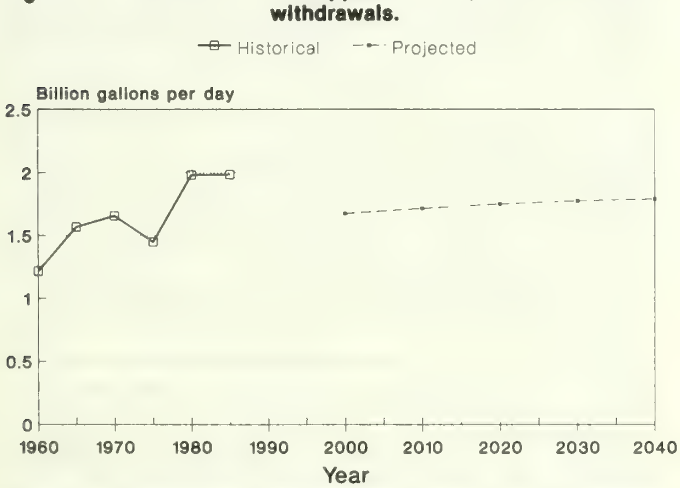

Figure 30.—Domestic self-supplied water, total freshwater consumption.

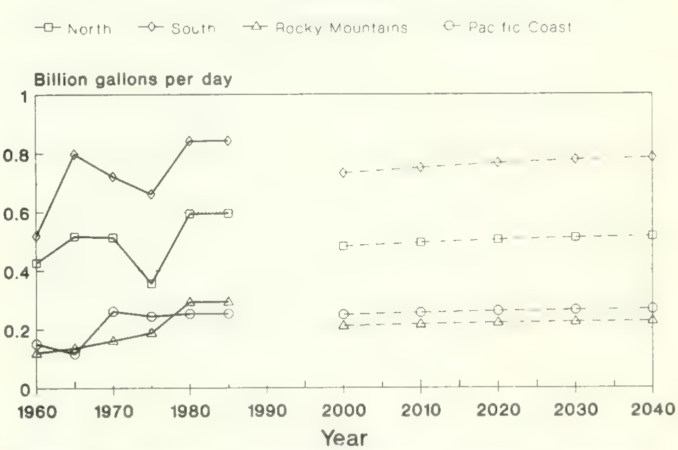

Figure 32.—Domestic self-supplied water, freshwater consumption by region.

LIVESTOCK WATERING USE

Livestock watering includes water provided for drinking by livestock and water used to maintain livestock sanitation. It includes the water pumped by windmills to stock ponds on western rangeland and water used to flush manure from dairy barns and feedlots into a waste holding lagoon. Since 1985, it also includes water used on farms for aquaculture and other non-irrigation purposes.

The heaviest use for livestock watering occurs in regions with high livestock populations. The Missouri, Arkansas-White-Red, Texas-Gulf, Upper Mississippi, Ohio, Mid-Atlantic, and South Atlantic-Gulf are water resource regions with the largest livestock watering withdrawals. Red meat production and dairying are major industries in those regions.

Water use and trends.—The quantity of water withdrawn for livestock and aquaculture in 1985 was 4.5 bgd, twice the quantity withdrawn in 1980 (fig. 33). Consumption showed a 20% increase (fig. 34). The large increase in use is attributed to an acceleration in aquaculture—fish farming. Growing fish for human consumption emerged as a rapid-growth industry in Idaho (salmon and rainbow trout) and Mississippi and Arkansas (catfish). These three states accounted for 42% of the Nation's total livestock and aquaculture water use, largely because of increases in aquaculture (Solley et al. 1988) (figs. 35 and 36). A related reason for the doubling of livestock and aquaculture water use since 1980 is that some states previously reported water use for fish farming in the industrial self-supplied category. In 1985, all aquaculture use is consolidated in the livestock category.

Potential for changes in the projections.—Livestock watering needs are a function of animal populations, which in turn, are a function of demand for red meat, dairy products, and fish. Basic assumptions for the Assessment include a projection of red meat demand at 110 pounds per capita per year—a demand assumed constant between 2000 and 2040.[4] Thus, demand for red meat and dairy products is projected to grow at the same rate as population.

Since the Assessment in 1979, there has been a marked change in per capita consumption of red meat. Recent scientific studies linking diet to coronary heart disease and other maladies concluded that animal fat plays a role in increasing risk of heart attack. Consumers responded to these findings by reducing annual consumption of beef and pork and increasing consumption of poultry and fish. Beef producers responded to the change by altering cattle production to reduce beef fat content. This was accomplished by reducing the length of feedlot stays and boosting forage consumption. It is too early to determine whether red meat consumption will recapture market

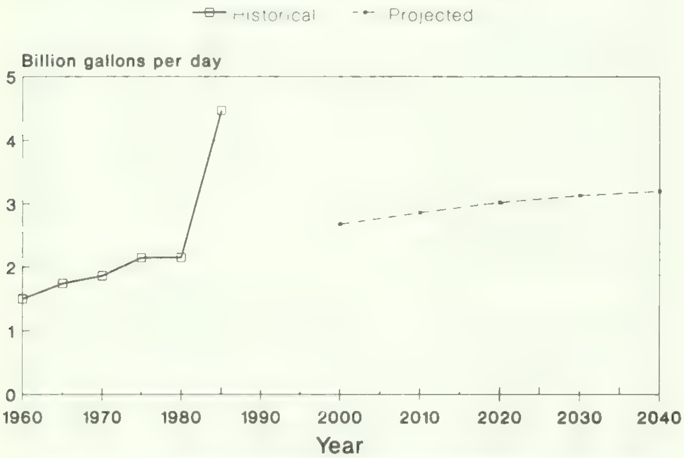

Figure 33.—Livestock watering, total freshwater withdrawals.

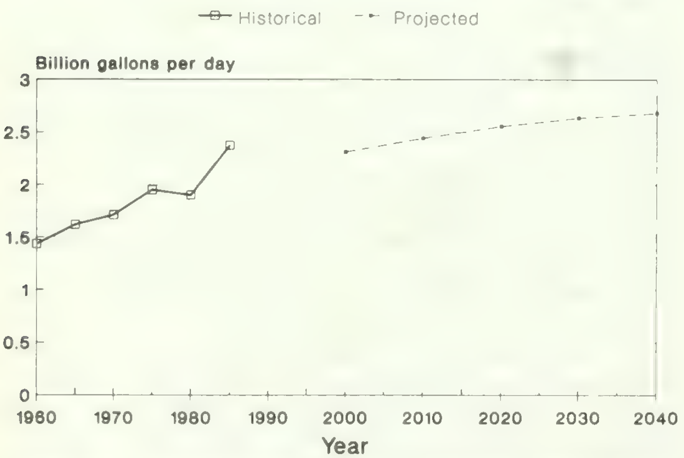

Figure 34.—Livestock watering, total freshwater consumption.

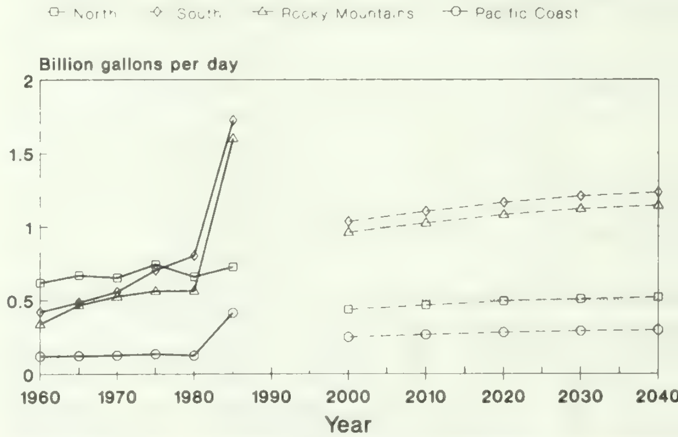

Figure 35.—Livestock watering, freshwater withdrawals by region.

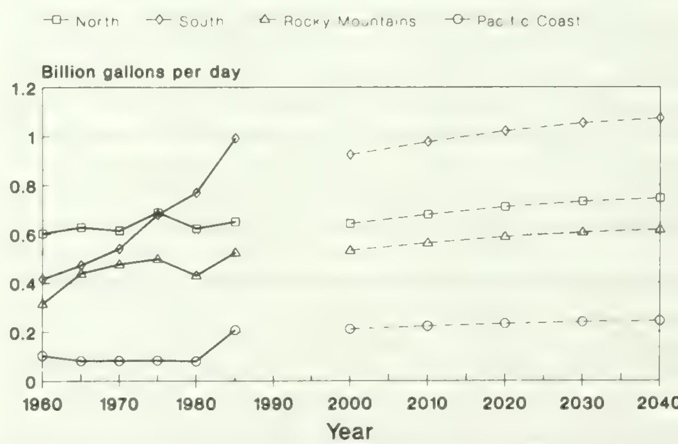

Figure 36.—Livestock watering, freshwater consumption by region.

share and rise back to previous consumption levels. If this occurs, the cattle population will increase and livestock water use levels will be affected. Joyce (1989) discusses the relationship of domestic beef production and imports to future demands for red meat.

Projections of livestock water use reflect historical trends where aquaculture was not a significant component of livestock water use. If a permanent change in meat demand occurred so that poultry and fish consumption remains high compared to red meat, then projections of withdrawals reported here will most certainly underestimate future withdrawals (figs. 33 and 35).

The main use of withdrawals for fish farming is to refill existing ponds and fill new ponds. Pond levels are lowered as part of the production cycle; water drained off typically moves to surface streams. This is why livestock water consumption does not show the large increase that withdrawals show. Pond evaporation is the main consumptive water use. If aquaculture continues to grow as in the past five years, withdrawals will increase significantly by 2000.

COMPARISON WITH PREVIOUS PROJECTIONS[5]

Forecasts of water use were made over the past three decades by many agencies and commissions. Notable examples are studies by the Senate Select Committee on National Water Resources (U.S. Congress 1961), Wollman and Bonem (1971) in a Resources for the Future publication, The National Water Commission (1973), and the Water Resources Council (1978).

When the Second National Water Assessment (Water Resources Council 1978) was released, there was much discussion about its projections because they deviated significantly from projections made by the Senate Select Committee (SSC), the National Water Commission (NWC), and Wollman and Bonem (RFF). Viessman and DeMoncada (1980) presented a comparison of withdrawal and consumption projections to the year 2000 from SSC, RFF, NWC and WRC. They noted that all projections have underlying assumptions. For the most part, population, economic activity, and technological factors were important factors determining projected water use levels. They also pointed out that projections such as those in the studies cited are only intended to guide decisions and are not to be accepted as "hard" forecasts of the future. The same point was made earlier in this chapter for projections presented here. This section reviews previous projections and compares them to the projections updated in this Assessment in light of the withdrawal and consumption data gathered by USGS since previous studies. The year 2000 will be used as the focus for making comparisons because that year is common to all projections.

Senate Select Committee on National Water Resources.—The SSC estimated that total freshwater withdrawals in 2000 would reach 888.4 bgd. This is about 2.5 times total withdrawals in 1975. Consumption in 2000 was projected at 156 bgd, an increase of 62% over the 1975 level. A medium level population projection of the 48 contiguous states was used—244 million in 1980 and 329 million in 2000. Other assumptions were: the economy would grow at the same rate as in the past; adequate water supplies will be available under prevailing general pricing policies; industrial water use will grow at a high rate; and with the exception of improved irrigation efficiency, existing inefficient methods of water use will continue.

Projections by Wollman and Bonem.—The RFF study of water use was an outgrowth of work done by the SSC. Projections were made for 1980, 2000, and 2020 based upon assumptions of high, medium, and low rates of economic growth. Wollman and Bonem state that their findings were neither predictions nor projections. Rather, they were an attempt to portray the problem likely to be encountered if current trends continue. Estimates of withdrawals and consumption were based on projected patterns of population and economic activity in conjunction with appropriate water use coefficients. Population projections for 1980, 2000, and 2020 were used as the basis for projecting levels of water use in the U.S. Population projections were used to estimate municipal water use and waste, waste collection costs, rural domestic requirements, and to update projections of the food processing industry. It was assumed that regional economic activity would grow or decline relative to growth of the national economy at rates consistent with trends at that time. Estimates of GNP and other indices were used to arrive at projections of other industrial water uses. The net result was that withdrawals were projected to be 563 bgd under the medium growth scenario and 1128 bgd under the high growth scenario. Consumption was projected to be 148 and 190 bgd respectively for the medium and high scenarios.

The National Water Commission Projections.—In its 1973 report on Water Policies for the Future, the NWC commented that variables in policy and technology combined with hard-to-forecast growth rates in population and economy tend to cast doubts on projections of future water needs based only on past trends. They devised a variety of alternative futures in which factors affecting water use were explicitly considered. The NWC analysis incorporated four levels of population and a variety of assumptions about water demand and supply variables. The result was a set of three trends in withdrawals and consumption. Withdrawals were 1510, 1000, and 490 bgd respectively for the high, medium, and low trend scenarios. Consumption projections were 185 and 125 bgd for the high and low trends.

Compared to other projections, the NWC high scenario is by far the largest. Assumptions inherent in this scenario called for no change in industrial self-supplied and thermoelectric steam cooling withdrawals and a continuation of once-through cooling with no limitations on temperatures of waste flows discharged to streams. The NWC report acknowledged that substantial reductions in withdrawals would result from adoption of advanced cooling technologies. Other scenarios use this cooling technology to varying degrees.

Second National Water Assessment.—The second National Water Assessment released in 1978 concluded that

many changes occurred since its first report in 1968. It was noted that population had not grown at the rate anticipated in the previous assessment and that greater awareness of environmental values, water quality, groundwater overdrafts, limitations of available water supplies, and energy concerns were having a pronounced impact on water resources management.

The WRC water use projections called for withdrawals of 306 bgd and consumption of 135 bgd by the year 2000. The amount of water withdrawn for manufacturing is projected to decrease by about 60% by 2025, accompanied by an increase of 137% in consumption. Withdrawals for power generation are anticipated to decrease by about 24% by 2025 due to conversion from once-through cooling to cooling towers. This decline is expected to be accompanied by a substantial increase (600%) in water consumption. However, because consumption was less than 0.5% with once-through cooling, an increase of the magnitude projected would still leave consumption below 3% of total withdrawals. The first national water assessment conduced by the WRC was released in 1968. Withdrawals were projected to be 804 bgd and consumption 128 bgd in the year 2000.

In a study of national water supply problems, the General Accounting Office (GAO 1977) questioned WRC's assumptions on industrial water withdrawals because stringent assumptions of the Clean Water Act may be modified. Further, GAO believed that industries may find it cheaper to continue using water on a once-through basis with wastewater treatment than to construct costly recycling facilities.

The WRC also projected that irrigation water withdrawals are expected to decline about 8% from 1975 to the year 2000 because of increasing depletions of deep groundwater in southwestern regions. Consumptive use in that sector was also expected to increase less than 2% because of water use conflicts and the likelihood that no new large-scale irrigation projects will be publicly funded. GAO challenged these premises, citing that in northerly regions, water and agricultural conditions were more suitable for irrigation increases than in the Missouri and Souris-Red-Rainy water resource regions. They also challenged WRC assumptions concerning slower growth in food and fiber requirements and that no new large-scale irrigation projects would come to pass.

COMPARISON OF THE DEMAND PROJECTIONS

Historical freshwater withdrawals and consumption are plotted along with projections from various sources in figures 37 and 38. Data for 1980 and 1985 are also plotted on the chart. These more recent data clearly show that withdrawals and consumption trends have followed the WRC 1978 water projections. Analysis of the WRC assumptions reveals that in the past decade, many of their assumptions have been upheld—more so than the GAO report believed. The result appears to be a major structural change in long-term trends for withdrawals and consumption, stemming largely from changes in na-

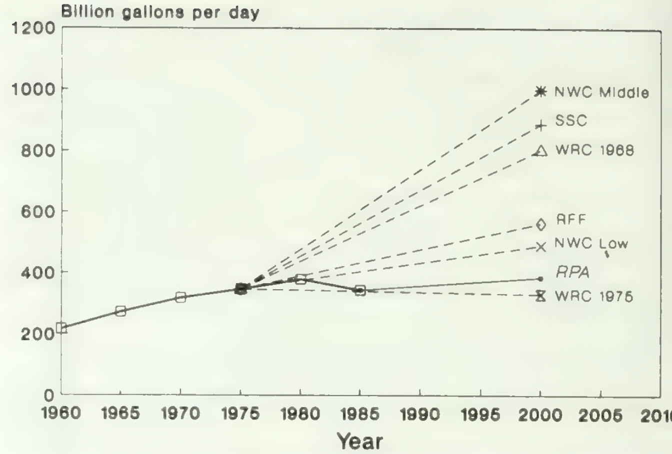

Figure 37.—Freshwater withdrawals, 1960-1985, with projections from other studies to the year 2000.

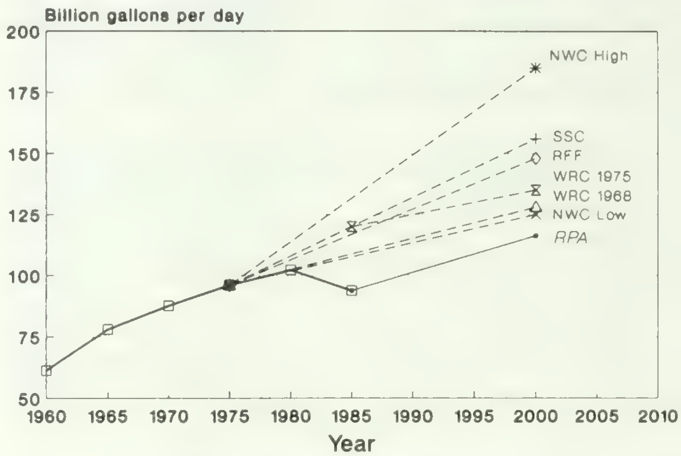

Figure 38.—Freshwater consumption, 1960-1085, with projections from other studies to the year 2000.

tional water resource policies due to legislation of the early 1970s.

Osborn et al. (1986) studied the SSC and WRC projections from the first national water assessment. They compared projections of water use with estimates of actual use in 1980 to assess the accuracy of water use forecasts. They concluded that water use projections must be based on methods that help explain effects of water demand determinants on use. Further, they concluded that a detailed analysis of factors that have influenced recent trends in withdrawals and consumption was needed. Recent federal planning guidance (Water Resources Council 1983) has paralleled these findings, calling for specification of factors underlying historically observed patterns of water use and requiring application of statistical techniques to estimate relationships between water use and explanatory variables. The demand analyses in this report have followed those guidelines.

SUMMARY

Total demand measured by withdrawals amounted to 343.7 bgd in 1985 and is projected to rise to 526.6 bgd in 2040. Surface sources provided 75% of withdrawals

in 1985; this is projected to rise to 78% in 2040. Total demand measured by consumption amounted to 93.8 bgd in 1985 and is projected to rise to 143.1 bgd in 2040.

Irrigation is the largest withdrawal use and also the largest consumptive use of water today and is projected to remain the largest consumptive use to 2040. Consumption by irrigation in 1985 totaled 73.8 bgd and is projected to rise to 101.1 bgd by 2040. The largest demands for irrigation will be in the Rocky Mountains and Pacific Northwest and the fastest growth will be in the North.

Thermoelectric steam cooling is the second largest withdrawal use of water and is projected to become the largest withdrawal use by 2040. Withdrawals for cooling in 1985 totaled 130.4 bgd and are projected to increase to 228.3 bgd in 2040 due mainly to the projected increase in electricity needed by an expanding economy. Coal will remain the predominant fuel throughout the projection period.

Demands projected in this Assessment for the year 2000 are lower than levels projected in previous studies. However, recent demand data indicate a structural change in demand due to pollution control requirements of the Clean Water Act. Projections in this report account for the structural change.

Implications of demand projections presented in this chapter will be discussed further in Chapter 6. But first, the quantity of water available for use—water supply projections—must be presented (Chapter 4) and comparisons made between projected demands and supplies to identify regions and timeframes where water shortages are likely to occur if water resource management continues as it has in recent years (Chapter 5).

NOTES

1. Survey procedures in the first two studies (MacKichan 1951 and 1957) focused on withdrawals. Very little data on consumption was provided. MacKichan and Kammerer (1961) provided the first estimates of consumption by use and by state. Because water that is withdrawn but not consumed is returned to streams after use, it is available for subsequent withdrawals downstream. Water that is consumed, on the other hand, is not available for withdrawal and use downstream. Hence, consumption data is the more limiting for estimating demand. Analyses begin with 1960 data, the first year specific consumption data is available.

2. Electrical generating capacity in the U.S. could be increased 15% without building new power plants and the cost of operating generators could be cut 60% if the newly-invented "high temperature" superconducting materials can be made practical (Rensberger 1988). These estimates were made by researchers at the Argonne National Laboratory in collaboration with five other major energy research centers.

3. The difference between the 105 gpd figure cited here and the 184 gpd figure cited in the municipal self-supplied section is that the 184 gpd includes total volume of water supplied by central systems to commercial and industrial establishments and for public uses.

4. Veal and lamb, the two other components of red meat demand, are projected at a constant four pounds per capita per year over the projection period. Pork consumption is also projected to remain constant at 60 pounds per capita annually. See Darr (1989) for additional details.

5. Information about historical studies in this section of the report is drawn largely from Viessman and DeMoncada (1980). Data for 1980 and 1985 come from Solley et al. (1983) and Solley et al. (1988).

CHAPTER 4: THE SUPPLY SITUATION FOR WATER

The supply of water has two components—quantity and quality. The focus of this chapter is on projecting water supplies and related land resources to 2040. This chapter begins with a discussion of the quantity aspects of supply and quantity projections over time. Effects of irregular occurrences of oversupply (floods) on land and developments are reviewed. A discussion of projected water quality follows. The chapter concludes with an overview of trends in the supply of wetlands. Existence of wetlands is related both to water supply and water quality trends.

WATER SUPPLY QUANTITY

Analysis of the supply of water is different from analysis of the supply of other renewable resources. For timber, forage, outdoor recreation and wilderness, and wildlife and fish, managers can take steps to increase the quantity of the resource available for use in the long run. For water and minerals, on the other hand, supplies are essentially constant over time. Minerals are a "stock" resource[1] which, for all practical purposes, cannot be renewed in the period covered by this Assessment. Water, on the other hand, is a renewable resource in the sense that rain falls each year to replenish surface water and groundwater. Yet, there is little that water managers can do to influence the quantity of rain that falls in a given year[2]. So, in a sense, water supply is a hybrid—a renewable resource because rain falls each year and a stock resource because the quantity of precipitation expected each year is the long-term average incapable of being altered significantly over wide areas by managers.

In Chapter 2, the current resource situation for water was discussed. A generalized water budget was presented that accounted for groundwater depletion rates and instream flows necessary for optimum wildlife and fish habitat (table 2). A generalized budget was developed based on supply (the average annual streamflow) expected in a year of average precipitation (the annual precipitation expected to be exceeded 50 percent of the time). In drier years, less precipitation and less annual streamflow are expected. For comparison, two additional supply scenarios are presented (table 12). The 80% level represents average annual streamflow expected with an annual precipitation level that is expected to be exceeded 80% of the time (8 out of 10 years). The 95% level represents average annual streamflow expected with an annual precipitation level that is expected to be exceeded 95% of the time (19 out of 20 years). Annual precipitation rates and streamflows lower than the average can be expected 5 years in 10. Annual precipitation rates and streamflows lower than the 80% level can be expected to occur 2 years in 10. Annual precipitation rates and streamflows lower than the 95% level can be expected 1 year in 20. So the 80% and 95% precipitation levels represent droughts of two different severities.

ADEQUACY OF INSTREAM FLOW[3]

Optimal habitat.—Sixty percent of average flow is the base flow recommended to provide excellent to outstanding habitat for most aquatic life during their primary periods of growth and for the majority of recreation uses (Tennant 1975). Channel widths, depths, and velocities at this base flow will provide excellent aquatic habitat. Most normal channel substrate will be covered with water, including most shallow riffle and shoal areas. Side channels that normally carry water will have adequate flows. Few gravel bars will be exposed and the majority of islands will serve as wildlife nesting, denning, nursery, and refuge habitat. The majority of stream banks will provide cover for fish and safe denning areas for wildlife. Pools, runs, and riffles will be adequately covered with water and provide excellent feeding and nursery habitat for fishes. Riparian vegetation will have sufficient water. Fish migration is no problem in any riffle areas. Water temperatures should be adequate for fish. Invertebrate life forms should be varied and abundant. Water quality and quantity should be suitable for fishing and floating canoes, rafts, and larger boats, and general recreation. Excellent to outstanding stream aesthetics and natural beauty will be maintained.

Good survival habitat.—Thirty percent of the average flow is a base low recommended to sustain good survival habitat for most aquatic life forms (Tennant 1975). At this base flow level, channel widths, depths, and velocities will generally be satisfactory. Most substrate will be covered with water except for very wide, shallow riffle or shoal areas. Most side channels will carry some water. Most gravel bars will be partially covered with water and many islands will provide wildlife nesting, denning, nursery, and refuge habitat. Stream banks usually will be sufficient to provide cover for fish and wildlife denning habitat. Many runs and most pools will be deep enough to serve as cover for fishes. Riparian vegetation will not suffer from lack of water. Large fish can move over most riffle areas and water temperatures are not expected to become limiting in most stream segments. Invertebrate life is reduced but not expected to become a limiting factor to fish production. Water quality and quantity should be good for fishing, floating, and general recreation, especially with canoes, rubber rafts, and smaller, shallow draft boats. Stream aesthetics and natural beauty will generally be satisfactory.

Poor survival habitat.—Tennant (1975) described conditions for 10% of average flow. This flow rate is the minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. Channel widths, depths, and velocities will all be significantly reduced and aquatic habitat degraded. Stream substrate or wetted perimeter may be about half exposed except in wide, shallow riffle or shoal areas where exposure could be higher. Side channels will be severely or totally dewatered. Gravel bars will be substantially

Table 12.—Expected annual stream outflows (billion gallons per day) resulting from variations in precipitation levels and instream flow requirements by water resource region

Water resource region	Expected average annual stream outflow[1] Mean[3]	80%[4]	95%[4]	Instream flow requirement[2] Mean	Dry
New England	76.8	61.4	46.8	69.0	46.1
Mid-Atlantic	93.9	72.3	57.3	68.8	56.3
South Atlantic-Gulf	207.5	147.3	110.0	188.7	124.5
Great Lakes	73.9	57.6	45.1	63.9	44.3
Ohio[5]	137.7	108.9	79.9	122.0	82.6
Tennessee	42.9	37.3	32.6	38.5	25.7
Upper Mississippi[6]	79.8	59.8	42.3	69.7	47.9
Lower Mississippi[7]	463.7	301.4	213.3	359.0	278.2
Souris-Red-Rainy	7.2	4.0	2.2	3.7	2.2
Missouri	51.7	34.6	20.2	34.0	15.5
Arkansas-White-Red	57.2	33.7	19.4	46.2	17.2
Texas-Gulf	31.2	13.4	6.9	22.9	9.4
Rio Grande	2.2	.6	.4	2.3	0.7
Upper Colorado	7.9	5.5	3.1	8.0	2.4
Lower Colorado[8]	1.6	1.4	1.2	6.9	0.5
Great Basin	4.6	2.8	2.1	3.4	1.4
Pacific Northwest	279.8	232.2	195.9	214.0	169.7
California	69.4	43.0	28.4	32.6	20.8
Alaska	921.0	801.3	709.2	797.3	553.6
Hawaii	13.6	9.9	7.6	11.8	8.2
Caribbean	4.8	3.3	1.5	4.2	2.9

[1]*The average annual stream outflow expected given three different expectations about precipitation levels.*

[2]*The instream flow requirements for the mean precipitation expectation provide optimal fish and wildlife habitat (Water Resources Council 1978). Instream flow requirements for good survival habitat in dry years are assumed to be 60% of average annual streamflows arising from the mean precipitation level for the New England, Mid-Atlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee, Upper and Lower Mississippi, Pacific Northwest Alaska, Hawaii, and Caribbean regions. In the other regions, the instream flow requirements for good survival habitat in dry years are assumed to be 30% of annual streamflow arising from the mean precipitation level (Tennant 1975 and Flickinger 1987).*

[3]*Average annual streamflows for the year of average precipitation are from Foxworthy and Moody (1986, table 7).*

[4]*Average annual streamflows for the 80-percent and 95-percent precipitation expectations were estimated by computing the percentage reductions in supply presented in U.S. Forest Service (1981, table 7.10) and applying those to the mean flow rates from Foxworthy and Moody.*

[5]*The Ohio region estimates exclude outflows from the Tennessee region.*

[6]*The Upper Mississippi region estimates exclude outflows from the Missouri region.*

[7]*The Lower Mississippi regions estimates represent conditions in all the upstream regions (Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas White-Red regions).*

[8]*The estimates for the Lower Colorado region represent conditions in both the Upper and Lower Colorado regions.*

Source: After U.S. Forest Service (1981, table 7.10)

dewatered and islands will usually no longer function as wildlife nesting, denning, nursery, and refuge habitat. Stream bank cover for fish and fur animal denning habitat will be severely diminished. Many wetted areas will be so shallow they no longer serve as cover. Fish will generally be crowded into the deepest pools. Riparian vegetation may suffer from lack of water. Large fish will have difficulty migrating upstream over many riffle areas.

Water temperature often becomes a limiting factor, especially in the lower reaches of streams in July and August. Invertebrate life will be severely reduced. Fishing will often be very good in deeper pools and runs because fish will be concentrated. Many fishermen prefer this level of flow. However, fish may be vulnerable to over harvest. Floating is difficult even in a canoe or rubber raft. Natural beauty and stream aesthetics are badly degraded. Most streams, at times, carry less than 10% of the average flow. From this description, it is plain that if streamflows less than 10% of the mean annual streamflow occur for several weeks, this low flow rate will usually have serious adverse effects on aquatic habitat.

Instream Flow Rates and Regional Water Balances

When instream flow requirements for optimal habitat (Water Resources Council 1978) and good survival habitat (Tennant 1975 and Flickinger 1987) are compared with instream flows based upon precipitation expectations (table 12), several points are worth noting. First, even with average precipitation, the Rio Grande, Upper

Instream flow levels providing good survival habitat for wildlife and fish also provide sufficient water for fishing, floating, and general recreation.

and Lower Colorado, and Great Basin areas will not have enough water instream to meet optimal habitat requirements. Second, and a counterpoint to the statement just made, only the Texas-Gulf and Rio Grande regions cannot provide good survival habitat in drought years. Although habitat is not optimum, flows in dry years in western regions nevertheless provide good habitat for survival. Only in the Rio Grande water resource region will dry-year precipitation at less than the 80% level not provide satisfactory survival habitat. Third, in the year of average precipitation, flows in eastern water resource regions provide optimal fish and wildlife habitat. Even in the 80% year, flows are significantly greater than minimums necessary for good survival habitat. Fourth, precipitation expected 1 year in 20 will result in flows less than those necessary for good survival habitat in the South Atlantic-Gulf, Ohio, Upper and Lower Mississippi, Texas-Gulf, Rio Grande, Hawaii, and the Caribbean water resource regions.

To this point, discussion has focused on annual precipitation and average flow rates. It is well known, however, that precipitation is not distributed uniformly throughout the year in many parts of the U.S. Thus, there are often times when suboptimum flow rates occur. Many water resource regions have main streams and tributaries whose flows are well below the good survival habitat level at some time during the year—even during a year of relatively abundant precipitation. Many streams also approach or go below the minimum short-term survival flow level.

Daily and seasonal flow variations in streams are not only a function of precipitation, but also a function of water control practices associated with reservoirs and dams. There are four major uses of stream flows that are served by reservoirs and dams. They include flood control, irrigation, navigation, and generation of electric power.

In the western regions, because of poor seasonal distribution of precipitation (much falling as snow), reservoirs have been built to capture springtime runoff primarily for irrigation and flood control purposes. Instream flow rates in western regions are rarely optimal, but also seldom less than the levels necessary for good survival habitat. Only the Texas-Gulf and Rio Grande regions cannot provide good survival habitat when precipitation falls to the 95% level (more precipitation expected in 19 out of 20 years).

Water control practices associated with dams on the Ohio and Mississippi Rivers to enhance navigation cause a more serious impact on the adequacy of instream flows. Good survival habitat cannot be maintained in exceptionally dry years. Navigation water releases are a function of barge traffic. When barges are not using the locks, minimal water may be released to assure sufficient volume for commercial needs in dry periods.

Hydroelectric releases are a function of electricity needs. Hydropower reservoir discharges vary widely during the day in response to fluctuating demand for electricity. Because of increased use of air conditioning and the switch to electricity as a preferred energy source in the mid-1970s, peak electricity demands on midsummer weekday afternoons often result in water releases for hydroelectric purposes that are many times the off-peak release rates. In the mid- and southern Appalachians, reservoir releases for recreation are becoming more prevalent. White water rafting schedules are

coordinated among outfitters and reservoir operators such as the Corps of Engineers to guarantee quality recreation experiences. High release rates are common on weekend mornings.

All these factors contribute to wide daily or hourly fluctuations in flow rates in rivers. Fluctuations can have negative as well as positive impacts on wildlife and fish habitat and other instream water uses. In recent years, maintaining adequate wildlife and fish habitat has become an important factor that reservoir operators must consider when planning operations directed primarily at satisfying other needs.

The effect of forests and other vegetation on runoff and streamflows, especially in reducing wide variations in flow, has long been known. Troendle (1983) and Douglas (1983) summarized the state-of-the-art about using vegetation management to influence timing of streamflows. They concluded that timber harvesting patterns and frequencies can be planned to trap snow at high elevations and extend snowmelt into the summer. The result is that high springtime peak flows are reduced. It has also been demonstrated that maintaining vegetation keeps soil infiltration and percolation rates higher than on bare sites. Thus, less runoff occurs and storm flow peaks are reduced. Many suburban areas have adopted zoning regulations in recent years specifying the use of vegetated areas to delay or temporarily store runoff and cut peak storm flows. In rural settings, managing riparian vegetation accomplishes the same objective. These nonstructural methods are now viewed as realistic alternatives to structural methods, such as dam construction and channelization, for reducing wide swings in streamflows.

FLOODING

The principal question in the preceding discussion about adequacy of instream flows focused on water shortages. In contrast, flooding impacts result from water excesses. In 1985, despite state-of-the-art communications and weather forecasting models, 44 people were killed by floodwater and property damage totalled more than $366 million (USGS 1986, table 1). Not included in these estimates was Hurricane Elena, which caused hundreds of millions of dollars in damage and resulted in the evacuation of a million people.

Almost half of all flood damages are to agriculture. Crops and livestock are destroyed and soil is washed away. Two-thirds of the total flood damages occur in rural areas. In urban areas, flood damages destroy homes and places of employment. The Federal Emergency Management Agency (FEMA) determined that about 20,000 of the 34,000 communities in the United States have some flood hazard areas (FEMA 1986). Flood-related costs also include funds spent for relief and reconstruction, lost productivity, and the general disruption of local and regional economies during and after a flood.

The impact of flooding on wildlife, fish, and ecosystems is mixed. In upstream areas, wildlife food and habitat are often washed away or covered with flood debris causing severe damage to natural systems. In some cases, however, flooding may transport beneficial nutrients that improve downstream ecosystems. For example, when the Bonnie Carret Spillway on the Mississippi River above New Orleans is opened (a mile-long series of floodgates) to divert floodwater into Lake Pontchartrain, shrimping in the lake that year is adversely affected due to the silt and the decline in salinity. However, two or three years after a spillway opening, nutrients brought by flood waters work their way up in the ecosystem and shrimp populations and sizes soar for a year or two.

Since 1941, annual flood damages in the U.S. have not been less than $50 million. Average annual damages between 1940 and 1970 exceeded $500 million (1984 dollars). Annual damages have exceeded $5 billion several times since 1970, the highest being $12 billion in 1972 when Hurricane Agnes devastated the Susquehanna River basin.

Despite increasing trends in annual flood damages,[4] there is no evidence that storms are increasing in magnitude or frequency. Increases in damages result from intensified development in flood-prone or flood-susceptible areas (Water Resources Council 1978) and from concentrating higher-valued agricultural production on flood plains (Department of Agriculture 1987).

Average annual flood damage per square mile varies considerably among water resource regions. The wide variation is related partly to weather patterns, partly to regional stream character, and partly to values of streamside property subjected to flooding.

Floods have serious effects on humans outside the flooded area. Floods overrun sewage treatment facilities often located along streams. Resulting contamination of flood waters and everything flood waters touch impacts public health in both physical and psychological senses. Many problems continue long after flood waters recede. The yearly loss of life from floods has usually been less than 100, but exceeded 500 in 1972.

Floods can be devastating or beneficial to agricultural interests. They can wipe out crops and dump tons of infertile sand, gravel, clay, and other debris on productive lands. Floating debris, such as trees and parts of buildings, can cause significant damage to bridges, culverts and roads, and other structures in the floodplain. Loose debris that is carried in floods often forms dams when trapped against bridges. These obstructions often cause flood waters to carve out alternate routes past the flow constriction, thus eroding abutments and approaches to the bridges or damaging additional structures as a pool forms behind the dam. If the debris dam breaks, such as when a bridge is washed off its supports, the resulting surge of water and debris can cause additional damage to structures downstream. On the positive side, slow-moving floods can deposit fertile, highly-productive sediments on cropland and wetlands. The infusion of nutrients can boost crop, wildlife, and fish production in subsequent years.

Average annual flood damages are projected to increase to $6.7 billion (1987 dollars) by the year 2000

Two-thirds of annual flood damages occur in rural areas.

(Forest Service 1981). Agricultural damages are expected to be more than $2.7 billion in 2000 while urban damages are projected to increase by 36% to $2.5 billion. All other damages are expected to average about $1.5 billion. By 2040, total annual damages are projected to reach $9.7 billion. It was not possible to project deaths due to flooding because past annual totals vary widely.

Regional estimates and projections of flood damages are closely correlated with population densities. Highest damages are likely to occur in the South Atlantic-Gulf, California, and Missouri regions. Agricultural damages are most important in the Upper and Lower Mississippi and Missouri regions. However, they are also significant in the Ohio, Arkansas-White-Red, Texas-Gulf, Great Basin, California, and Pacific Northwest regions. Urban damages will be more prominent in California, New England, Mid-Atlantic, and the Great Lakes regions.

SUMMARY

This analysis of water supply quantity includes no assumptions about water consumption by offstream uses. That information is presented in Chapter 5 where supply and demand projections are compared. The quantity of precipitation is a stochastic variable in any given calendar year; consequently, so is streamflow. If precipitation is below normal, the chance of detrimental impact on fish and wildlife habitat and other instream uses increases. If precipitation is above normal, the chance of detrimental impact due to flooding increases. No long-term trends in precipitation have been observed this century; consequently, the quantity of water supplies has no discernable trend. Annual fluctuations are sufficiently large to make water resource management a challenge in spite of the absence of a long-term trend.

WATER SUPPLY QUALITY[5]

The natural quality of water in the Nation's streams and lakes is largely a reflection of the characteristics of the land and vegetation from which the water flows. Because of natural variations in land and vegetation, water quality in streams and lakes is neither uniform nor static. Water is constantly moving, even in lakes and reservoirs. As it moves, its quality changes. Quality is influenced by natural features, including geology, and topography, soil, and vegetation.

The natural quality of water is also affected by the actions of people. These include road construction, urban development, farming, mining, timber harvesting, livestock grazing, and discharge of municipal and industrial wastes. Acid deposition also affects natural water quality, both near and far from the point where chemicals are released to the atmosphere.

Water is often used and reused several times and for many purposes during its journey to the sea. Water quality can be improved or degraded as it is used and returned to a stream. Because water is ever-moving and ever-changing, quality is difficult to inventory and measure. Without good inventories of water quality over time, making projections is virtually impossible.

It is important to recognize that water quality determines its useability for specific purposes. Water quality can be suitable for one purpose but not be suitable for

another. For example, a clear alpine lake may be excellent for aesthetic enjoyment and trout fishing, but very poor for swimming because the water temperature rarely exceeds 50° F. Another example is natural water quality that is ideal for swimming and for fish, wildlife, and livestock consumption, but unsatisfactory for a particular industrial use because of dissolved solids such as iron.

BASELINE WATER QUALITY FROM FORESTS AND RANGELANDS

To show the relationship of water quality to its natural environment, water quality data from relatively undisturbed forest and range land watersheds is displayed by division, province, or section as described by Bailey (1976) (USDA Forest Service 1976)(table 13). Bailey's hierarchical system for land classification begins with the largest, broadest definition as a domain, and proceeds downward in size and in specificity through division and province to section, which is the smallest and most discrete unit. Each section describes a more or less continuous geographical area and is characterized by distinctive fauna, climate, landform (including drainage pattern), soil, and vegetation that distinguishes it from adjacent sections. Within such sections, ecological relationships between plants, soil, and climate are essentially similar, thus similar management treatments give comparable results and have similar effects on the environment. Ecoregions are considered to be biological and physical areas of specific potential.

The watersheds where quality data were collected were small (10 to 200 square miles), relatively undisturbed areas (no major land disturbing activities within at least the last 5 years). Each contained more than 90% forest or range land or both and had a minimum of 5 years (10 years when possible) of water quality records that included total dissolved solids, dissolved oxygen, water temperature, and suspended sediment. These data from STORET[6], show how baseline water quality parameters vary by ecoregion (table 13). Water quality in all of the undisturbed watersheds exceeds the minimum water quality standards of most states. There is, however, a substantial amount of variability in various measures of quality among divisions, provinces, and sections.[7]

The baseline water quality levels in table 13 represent the best water quality that can be attained from managing forests and rangelands. Thus, maintaining this quality in streams becomes the goal for forest and range managers. Management activities often result in changes in water quality. Some changes are short-term and others longer-term. Some changes have only a local effect; others are more regional. For example, timber harvesting in the South is usually followed by regeneration the following year. The speed with which vegetation reoccupies the harvested site means that bare soil is rarely exposed for more than three years. Consequently, harvesting and regeneration operations only impose a short-term effect upon water quality from site runoff. Timber harvests on southern National Forests average 40 acres in size. Water quality effects from runoff from such a small area will also tend to be localized. Through careful planning and attention to details in implementation, significant long-term adverse water quality effects from land management activities can be avoided or mitigated.

APPROACHES TO IMPROVING WATER QUALITY

The Clean Water Act determines how the Federal government and states regulate point- and nonpoint-source pollution. Although amended in 1977, 1981, and 1987, basic directives embodied in the original 1972 Act continue to guide the Nation's water pollution control programs.

Point Sources

Two types of approaches were established by the Act for controlling pollution from point sources. One is the technology-based approach and the other is a water quality-based approach. Technology-based controls consist of uniform EPA-established standards of treatment that apply to industries and municipal sewage treatment facilities. These effluent standards are limits on the amounts of pollutants that may be discharged to streams. Limits are derived from technologies available for treating wastewater and removing pollutants. Limits are applied uniformly to every facility in an industrial category regardless of stream condition into which the effluent is discharged.

Water quality-based controls, on the other hand, are based on water quality in the stream receiving the effluent. This approach relies on water quality standards set by the states on the basis of stream use (e.g. fishing and swimming) and criteria (or limits on pollutants) necessary to protect those uses. Individual discharge requirements are based on effluent quality needed to ensure compliance with water quality standards. Details on how these approaches are being implemented for point sources are described in Environmental Protection Agency (1987).

Point-source pollution is generated primarily by industries and municipalities and is generally incidental to forest and range lands. However, some operations associated with forest and range lands do generate point-source pollution. Some are relatively permanent and generate pollution on a year-round basis, and others are temporary or seasonal.

Common sources of potential point-source pollution on forest and range lands include rock crushing and gravel washing, log sorting and storage, wood processing, mining, food processing, developed recreation sites, feedlots, boats, remote work centers (logging and mining camps), summer homes, and organization camps. These point-sources of pollution are found in every region, though not all are considered pollution problems in all basins. In fact, pollution from these sources is generally not significant on a national basis, but can be

Table 13.—Concentrations of selected water quality parameters (at three percentiles of the data distributions) from undistributed forest and range watersheds in the United States, by division, province, and section

Division, province, and section	Total dissolved solids (mg/l)[1] Percentile[4]			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/l)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
1300 Subartic												
M1310 Alaska Range	50	90	120	90	95	100	.0	6.0	13.0	1	3	40
											(100)	(500)[5]
1320 Yukon Forest	43	63	80	95	98	100	.0	3.8	7.5	10	20	40[6]
2100 Warm Continental												
2110 Laurentian Mixed Forest												
2111 Spruce-Fir	62	91	120	79	90	104	.0	10.0	15.5	0	4	14
2112 Northern Hardwoods-Fir	68	104	132	77	87	98	.0	8.0	20.0	2	4	10
2113 Northern Hardwoods	25	29	35	89	97	105	.0	8.0	17.0	1	3	8
2114 Northern Hardwoods-Spruce	16	20	25	86	92	100	.0	4.0	19.0	1	2	5
M2110 Columbia Forest												
M2111 Douglas-fir Forest	70	100	150	85	91	97	3.0	4.0	9.0	10	40	60
M2112 Cedar-Hemlock-Douglas-fir	48	52	54	85	95	105	.0	63.0	11.0	2	5	10
2200 Hot Continental												
2210 Eastern Deciduous Forest												
2211 Mixed Mesophytic	14	16	18	87	93	100	4.5	10.0	16.0	2	4	17
2212 Beech-Maple	206	368	556	80	94	100	4.0	10.5	23.0	2	24	95
2213 Maple-Basswood + Oak Savanna	239	294	313	86	96	110	1.0	9.0	17.0	14	48	734
2214 Appalachia Oak	22	25	29	89	97	105	2.0	6.0	15.0			
2215 Oak Hickory	44	62	156	84	94	105	7.0	15.0	23.0	2	8	40
2300 Subtropical												
2310 Outer Coastal Plain Forest												
2311 Beech-Sweetgum-Magnolia-Pine-Oak	16	23	53	73	83	90	10.0	18.0	24.0	4	19	
2312 Southern Flood Plain	16	23	53	73	83	90	10.0	18.0	24.0	4	19	83
2320 Southeastern Mixed Forest	15	22	34	9*	98	105	9.0	16.0	23.0	3	7	20
2400 Marine												
2410 Willamette-Puget Forest	46	62	75	70	80	90	2.0	12.0	18.0	5	10	20
M2410 Pacific Forest	15	40	75	95	98	100	1.0	5.0	9.0	1	3	40
										(20)	(80)	(400)[5]
M2411 Sitka-Spruce-Cedar-Hemlock	34	48	65	92	95	98	4.0	8.0	11.0	1	2	8
M2412 Redwood Forest	52	87	124	95	98	105	7.0	12.1	18.0	3	26	118
M2413 Cedar-Hemlock-Douglas-fir	25	50	90	85	90	95	3.0	9.0	16.0	4	8	12
M2414 California Mixed Evergreen	50	120	150	93	97	99	8.0	14.5	21.2	6	45	175
M2415 Silver Fir-Douglas-fir	23	46	68	85	90	94	1.4	6.2	10.9	2	5	10
2500 Prairie												
2510 Prairie Parkland												
2511 Oak-Hickory-Bluestem	235	314	370	76	94	128	.0	13.0	22.0	17	55	214
2512 Oak + Bluestem	51	55	58	--	--	--	11.0	20.0	25.0	--	--	--
2520 Prairie Brushland												
2521 Mesquite-Buffalo Grass	240	270	280	83	94	100	12.0	19.0	26.0	2	8	80
2522 Juniper-Oak-Mesquite	244	278	290	83	94	100	11.5	19.0	25.5	2	8	80
2523 Mesquite-Acacia	250	280	295	82	92	100	12.0	19.0	26.0	2	8	80
2530 Tall-grass Prairie												
2531 Bluestem	352	868	1060	70	86	100	.0	9.0	19.5	24	80	199
2532 Wheatgrass-Bluestem-Needlegrass	149	155	161	79	83	90	4.5	9.5	20.0	448	508	650
2533 Bluestem-Grama	72	104	133	54	81	100	5.0	13.0	23.0	--	--	--
2600 Mediterranean												
2610 California Grassland	400	600	800	90	95	100	8.0	18.0	28.0	30	60	90
M2610 Sierran Forest	11	19	20	90	96	102	6.2	13.8	15.5	1	3	5
M2620 California Chaparral	300	600	800	90	94	98	7.2	17.8	24.1	10	20	30
3100 Steepe												
3110 Great Plains Shortgrass Prairie												
3111 Grama-Needlegrass-Wheatgrass	994	2189	3384	53	70	87	1.4	9.7	18.0	10	6000	16186
3112 Wheatgrass-Needlegrass[7]	235	257	269	70	80	87	.0	4.0	12.0	25	47	81
3113 Grama-Buffalo Grass	1491	1610	1730	80	92	104	4.0	13.0	21.0	118	188	258

Table 13.—Concentrations of selected water quality parameters (at three percentiles of the data distributions) from undistributed forest and range watersheds in the United States, by division, province, and section—Continued

Division, province, and section	Total dissolved solids (mg/l)[1] Percentile[4]			Dissolved oxygen (% saturation)[2] Percentile			Water temperature (degrees centigrade) Percentile			Suspended sediment (mg/l)[3] Percentile		
	15	50	85	15	50	85	15	50	85	15	50	85
M3110 Rocky Mountain Forest												
M3111 Grand Fir-Douglass-fir	32	48	57	87	94	99	1.5	8.0	15.5	1	6	22
M3112 Douglas-fir	25	140	400	76	83	110	.0	6.0	12.0	7	25	300
M3113 Ponderosa Pine-Douglas-fir	38	52	60	65	73	78	.0	4.0	11.0	2	4	9
3120 Palouse Grassland	200	250	300	60	70	80	2.0	10.0	17.0	50	500	5000
M3120 Upper Gila Mountains Forest	63	128	173	73	87	114	6.0	11.0	21.0	1	2	20
3130 Intermountain Sagebrush												
3131 Sagebrush-Wheatgrass	85	109	124	9	11	12	2.0	11.0	24.0	4	9	57
3132 Lahontan Saltbush-Greasewood	50	80	100	74	79	84	1.0	8.0	15.0	13	30	177
3133 Great Basin Sagebrush	70	80	100	73	80	90	1.0	8.0	15.0	2	25	1970
3134 Bonneville Saltbush-Greasewood	1000	1400	3200	70	80	90	2.0	9.0	15.0	10	30	2000
3135 Ponderosa Shrub Forest	55	59	66	75	85	95	1.0	14.0	19.0	5.6	17.5	59.5
P3130 Colorado Plateau												
P3131 Juniper-Pinyon Woodland + Sagebrush-Saltbush Mosaic	150	225	350	70	82	100	4.0	13.0	21.0	5	25	500
P3132 Grama-Galleta Steepe + Juniper-Pinyon Woodland	158	228	390	85	95	145	5.0	16.0	23.0	19800	24800	37900
3140 Mexican Highlands Shrub	427	915	1180	95	105	105	15.0	25.0	33.0	14200	68940	111000
A3140 Wyoming Basin												
A3141 Wheatgrass-Needlegrass-Sage	220	495	770	78	87	96	2.0	9.0	17.0	78	850	1622
A3142 Sagebrush-Wheatgrass	190	267	344	71	82	93	2.0	9.0	17.0	1	191	565
3200 Desert												
3210 Chihuahuan Desert												
3211 Grama-Tobosa	1900	2450	2990	100	120	130	8.0	18.0	27.0	12	55	86
3212 Tarbush-Creosote Bush	93	114	132	--	--	--	13.0	21.0	25.0	--	--	--
3220 American (Mojave-Colorado-Sonoran)												
3221 Creosote Bush	509	541	603	70	105	140	13.0	21.0	28.0	7	576	1030
3222 Creosote Bush-Bur Sage	600	700	800	60	70	100	13.0	26.0	32.0	1000	5000	200000

[1]*All solid material that passes through a filter membrane having pores of 0.45 micron in diameter. Measured in milligrams per liter (mg/l).*

[2]*The ratio of the amount of dissolved oxygen present in water at a given temperature to the amount of dissolved oxygen water can hold at that temperature, expressed as a percent.*

[3]*The inorganic particles larger than 0.45 micron in diameter carried in suspension by the water. Measured in milligrams per liter (mg/l).*

[4]*Percentile figures are determined from an analysis of a frequency distribution. The 50th percentile represents the median (midpoint) of the data and a range is selected in which 70% of the data falls between the 15th and 85th percentiles.*

[5]*Figures in parentheses are for streams with a major contribution from glacial melt and are for the same ecoregions as figures immediately preceding.*

[6]*Suspended sediment figures for Yukon Forest do not include that measured in the Yukon River which is a glacial melt river originating in Canada.*

[7]*These figures represent only the Black Hills portion of this ecoregion.*

NOTE—Numbers before the division, province, and section designations refer to lowland ecoregions as described in Bailey (1976) and displayed in USDA (1976). Letters with the numbers, i.e., M1310, P3131, A3142, etc., indicate highland ecoregions in which M = mountains, P = plateau, and A = altiplano (a high plateau or plain).

Source: Environmental Protection Agency. National Water Quality Data Storage and Retrieval Program (STORET), cited in USDA Forest Service (1981).

significant locally if not controlled. Both technology-based and water quality-based approaches are used to control pollution from forest- and rangeland-related point sources.

Nonpoint Sources

As in the case of point-source pollution, nonpoint-source pollution has two abatement approaches: regulatory and non-regulatory. Regulatory controls tend to apply where cause-and-effect relationships can be most easily established, although many exceptions exist. Examples include controls on runoff from mining, construction, and silvicultural activities in states where these are significant industries. Other nonpoint categories such as agricultural runoff are more likely to be subject to non-regulatory, or voluntary, controls, with incentives and technical support provided by a variety of state and federal agencies. Nonpoint pollution controls are often applied on a case-by-case basis and are administered at the local or state level.

The Association of State and Interstate Water Pollution Control Administrators (1985) provides the most complete recent survey on the extent of nonpoint-source pollution in the United States. The Association reported on nonpoint-source programs at the federal, state, and local levels as of 1984. They found 354 programs at the state and local level and 32 programs in 17 federal agencies that manage nonpoint-source-related activities and affect water quality.

The most frequently listed federal programs were those of the Soil Conservation Service, Forest Service, Office of Surface Mining, Bureau of Land Management, and U.S. Army Corps of Engineers. State programs ranged from dredge-and-fill permitting and fish and wildlife management to pesticide applicator licensing and coastal zone/floodplain management. Local programs listed most frequently included those of soil and water conservation districts and planning/zoning commissions, plus those involved with permitting well construction and septic systems and erosion/sediment control.

States reported that 69% of state and locally initiated nonpoint-source programs include some form of regulatory authority. Grants, loans, tax abatement, and other incentives are included in 14% of the state and local programs, with most of these programs directed towards agricultural activities. The states concluded that effective nonpoint-source programs require close cooperation among state, federal, and local governments, along with private interests and the general public.

Economic Impacts of Water Quality Improvements

Water quality improvements resulting from the 1972 Clean Water Act were reported in Chapter 2. Water quality in streams has been upgraded considerably since 1972. Yet progress to date has not been spread uniformly across the countryside. Emphasis since the 1972 legislation has been on cleaning up major point sources of pollution. The result has been that 47% of EPA grant dollars have been spent on 11% of grants, which were allocated to only 1% of the treatment plants nationwide (table 14)(Smit and Chapin, 1983).

Plants having less than 1.05 mgd in capacity account for 79% of treatment plants nationwide, but only 8% of nationwide treatment capacity. In contrast, plants having greater than 50 mgd capacity are only 0.6% of plants but account for 39% of treatment capacity. In funding construction of large plants first, the major point-source problems were addressed first.

There is a substantial backlog of wastewater treatment projects in small communities. The scheduled reduction in the construction grants program funded by EPA means that financial grants to small communities will drop. This construction grants program provided for the federal government to pay 75% of treatment plant construction costs. The new program will provide a federal grant of only 55% and make the communities eligible for low interest loans. For example, if the community finances its 45% of the cost through a loan from the Farmers Home Administration at 5% interest for 40 years, loan payments should result in user charges equivalent to charges needed to retire bonds sold at market rates to fund the 25% community share under the former program (Smit and Chapin 1983). As an additional incentive to small towns, treatment standards for small communities were reduced by the Municipal Wastewater Treatment Grant Amendments of 1981 to allow less-expensive treatment options that would still bring these towns into compliance with the Clean Water Act. These amendments declared that treatment processes such as trickling filters and lagoons met secondary treatment standards established for municipalities.

Feliciano (1982) summarized the economic impact of treatment plant construction grants in terms of jobs. His numbers have been modified here to convert them from a grant-dollar basis to a total-expenditure basis. Each $1 billion in expenditures for wastewater treatment plant construction provides 10,195 person-years of work for building trades, 14,660 person-years of work for industry (manufacturing, transportation and related services and mining), and 1,840 person-years of work for engineers for a total of 26,835 person-years of work. Adjustments made by the Municipal Wastewater Treatment Grant Amendments of 1981 reduced the capital-intensity of treatment plants for small towns, so job impacts of the future construction program combining grants and loans may be somewhat less. Nevertheless, the economic impact is still expected to be substantial. Further, because small towns are more uniformly distributed across the nation, the economic impact of the future program should be spread across the land. Smaller firms will have more opportunities to participate in the construction program.

Table 14.—Distributions of community size, number of grants, and value of grants for wastewater treatment plant construction, 1972 to 1982

Community size	Number of places	Number of grants	Value of Grants
		percent	
Less than 5,000	79	55	12
5,000 to 25,000	16	23	21
25,000 to 100,000	4	11	20
Greater than 100,000	1	11	47

Source: Smit and Chapin (1983)

STATUS OF STATE WATER QUALITY LAWS AFFECTING FORESTRY OPERATIONS

Most modern efforts to maintain or improve water quality in individual states have stemmed from the Clean Water Act. The amendments stressed strong state action and federal oversight to control water pollution. Although many states had enacted some water quality legislation prior to 1972, only a few laws specifically addressed silvicultural pollution of water. Most attention was given to stream blockage with logging debris.

Two sections of the Clean Water Act have direct implications for forestry operations. Section 404 requires a permit for discharging dredge and fill material into navigable waters and adjacent wetlands. Under this authority, the Corps of Engineers may require permits when drainage projects are conducted for certain silvicultural operations in wetlands, such as clear cutting, site preparation, and road and skid trail construction. Additional discussion about the 404 Program is found in the wetlands sections of this chapter and Chapter 8.

Section 208 mandates that individual states develop and implement areawide nonpoint-source pollution management plans subject to approval of EPA. Silvicultural activities are designated as one type of nonpoint-source pollution that plans must address. Thus, most state efforts with respect to water quality in recent years were in conjunction with Section 208. However, despite state activity that resulted from Section 208, many believe that nonpoint-source pollution was still an impediment in achieving national water quality goals. This led to a major revision of the law in the form of the 1987 Water Quality Act. A principal component in the new law, Section 319, contains specific language intended to improve control of nonpoint-source pollution.

Section 319 requires each state to prepare by August 1988 detailed water quality management plans that identify bodies of water not in compliance with water quality standards because of nonpoint-source pollution. Plans are also required to identify categories and individual nonpoint sources that violate water quality, and to describe proposed control mechanisms. Each state must then devise either regulatory or voluntary programs to control nonpoint-source pollution, including that emanating from forestry activities. In implementing voluntary or mandatory nonpoint control mechanisms, states may base compliance on either the use of BMPs or on state water quality standards.

BMPs are optional methods, measures, or practices for preventing or reducing water pollution and include (without limitation) structural controls, operating and maintenance procedures, and activity scheduling and distribution. Water quality standards, on the other hand, are specific water quality criteria, both narrative and numeric, for designated water bodies of a state.

Existing state water quality and related legislation was examined for this report, including how such laws interact with forestry activities and how individual states are currently addressing silvicultural-related nonpoint water pollution. Tables C–1 through C–4 in Appendix C present statutory details for each state, together with a brief discussion of implications of current legislation for silvicultural operations.

Each of the 50 states has in force a general water quality law. Some are more specific than others but all are broad in scope. Each statute authorizes the administering agency to control water pollution by promulgating standards and regulations. Some laws also prescribe a discharge permit system which is usually optional with the administering agency. Only a few of these general laws specifically address forestry operations and only a few distinguish between point and nonpoint sources of water pollution. Virtually all, however, are broad enough in language to encompass by implication nonpoint-source pollution, including that emanating from forestry activities, even though the statutory language fails to mention the terms "forestry or silvicultural" and "nonpoint."

The South.—Most general water quality laws in the South were passed in the 1960s and 1970s. In 11 of 14 southern states, neither the general statute nor regulations promulgated under it address forestry activities. Two states—Tennessee (by statute) and Louisiana (by regulation)—specifically exempt silvicultural operations from the Act's provisions. West Virginia includes forestry under its Act's umbrella except where site-specific silvicultural BMPs are utilized. All southern states except Texas use a voluntary forestry BMP program to control forestry-related nonpoint-source pollution. Texas has no program whatsoever and takes the position that no problems exist in the state. Some southern states have also passed special water-related laws covering stream obstruction, wetland protection, and scenic rivers that impact to some degree on forestry operations in special situations.

The North.—Each northern state has a general water quality law, most of which were enacted prior to 1960. Wisconsin's law was enacted in 1913. This type of statute has generally been in force longer in the North than in other parts of the country where most such laws are much newer. Some northern statutes (or the regulations issued under them) specifically address forestry operations, as do statutes in the West. But other northern states, primarily in the Midwest, have statutes that omit specific references to forestry. These laws, in general, parallel those in the southern states and are broadly enough written to apply by implication to silvicultural nonpoint sources.

Forestry nonpoint-source water pollution in the North is subject to a wide range of control mechanisms ranging from formal regulation in Massachusetts under that state's Forest Practice Act to no program whatsoever in Delaware and Rhode Island. Maine, New York, Vermont and New Hampshire utilize a quasi-regulatory approach with a tie-in to the general water quality law. Maryland, Connecticut, New Jersey, and Pennsylvania approach the situation with a voluntary BMP program. In certain cases, very large forestry harvesting activities in Pennsylvania are subject to state regulation under the general water quality law. Most northern states have also passed a variety of special wetland and shoreline protection

laws that contain restrictions on forestry practices in special situations. In addition, there are water-related laws that impact certain forestry operations relating to stream obstruction and scenic rivers statutes.

The West.—All but three general water quality laws in the West were passed in the 1960s and 1970s. Oregon and Utah statutes were enacted in the 1950s and Idaho's in 1947. Eight of 17 laws either specifically address forestry nonpoint pollution control in the basic legislation or do so by regulation or administrative procedure. In California, Idaho, Oregon, Nevada, New Mexico, and Washington, forestry water quality problems are controlled through state forest practice acts and mandatory BMPs promulgated under those laws. In Montana, forestry operations must adhere to BMPs developed by the Department of Public Lands. In Alaska, BMPs written under the authority of the state forest practice act are voluntary—thus if they are not utilized, or are used and fail to prevent violations set forth under the general water quality act, regulatory provisions of the latter can be invoked. In Utah, forestry nonpoint pollution is addressed through state certification of local BMPs as directed by regulations issued under the general water quality statute. Arizona, Hawaii, Colorado, Kansas, Nebraska, North and South Dakota,and Wyoming have no forestry nonpoint programs. A number of western states have enacted special water protection statutes that deal with stream obstruction, scenic rivers, and wetland protection that place limitations on forestry operations in special situations.

Summary

A review of state water quality legislation that affects forestry practices in the East indicates that most laws were not very restrictive to date with the exception of several northern states. However, the opposite situation exists in much of the West. In many situations in the East, however, statutes do have the potential to be more stringently invoked with respect to silvicultural operations. In addition, new state legislation is being considered in a number of eastern states to replace inconsistent, and often conflicting local land use ordinances, many of which address water resource protection. These laws could also result in more pervasive and strict control of silvicultural activities. Passage of the 1987 Water Quality Law with its strong emphasis on state action indicates that nonpoint-source water pollution prevention will continue to be both a national and state priority. New state laws will certainly be passed, and old ones amended, to address in more absolute terms nonpoint-source pollution from silvicultural activities.

WATER QUALITY IMPROVEMENTS SINCE LAST ASSESSMENT

Major advances have been made in improving instream water quality since 1972. Comparison of State reports in EPA (1987) with previous inventory reports demonstrates where and how much water quality has improved. Case studies in the 1987 report show even more impressive results obtained in specific areas.

The Clean Water Act set goals and the nation mobilized to attain them. The 1986 National Water Quality Inventory concludes that industries mobilized to clean up point sources faster than municipalities. In the decade following passage, biochemical oxygen demand loads from municipal plants decreased 46% and industrial loads at least 71% (Association of State and Interstate Water Pollution Control Administrators 1984). Costs of municipal wastewater treatment today are double those of 1972 (in constant dollar terms) and industrial costs are 50% higher. These expenditure patterns portray the additional emphasis water pollution received following passage of the Clean Water Act.

As point sources of pollution have been cleaned up, effects of nonpoint sources have become more apparent. If anything, their effect was underestimated when the original legislation was passed in 1972. Widespread increases in chloride (highway salting), nitrate (fertilizers), and sulfate (coal combustion products) concentrations are thought to be linked to nonpoint-source pollution (Foxworthy and Moody 1986). Sediment from soil erosion is also a major nonpoint-source pollution problem emanating mostly from agricultural areas.

Water quality programs that formerly emphasized control of point-source pollution are shifting to programs emphasizing control of nonpoint sources of pollution, protection of ground-water quality, and cleanup of toxic-waste disposal sites. This shift in emphasis is projected to continue into the next century because these problems are more difficult to address.

SUMMARY

Background water quality levels for undisturbed forests and rangelands represent long-run water quality goals that land managers seek to perpetuate. Before the mid-1960s, offstream uses downstream from forests and rangelands resulted in significant declines in water quality. Dilution of wastes with instream flows was a commonly accepted policy (Wollman and Bonem 1971). The Clean Water Act changed that policy and set goals of returning water to fishable and swimmable levels by 1983 and eliminating discharges causing pollution by 1985. The nation embarked on what has become a successful effort to clean up discharges. Efforts over the past 15 years have largely met the fishable-swimmable goal. Cleanup cost has been considerable—$300 billion for pollution abatement between 1972 and 1984 and $172 billion for capital equipment alone.[8]

It is unlikely that the nation will soon embark on a program of similar magnitude. Any additional cleanup will require larger investments to obtain much smaller increments of improved water quality; successive increments of pollution become more and more costly to remove. Consequently, one cannot take improvements made in water quality since 1972 and project that additional improvements will continue at that rate.

The quality of water supplies available nationwide after 2000 will be somewhat better than current quality, but a major improvement nationwide is not anticipated. The opportunity for the most significant improvements in quality will come from reductions in nonpoint-source pollution. The prevalence of municipalities and industries causing locally significant water quality problems will diminish as smaller point-source discharges are cleaned up.

The quality of water emanating from forested and rangeland watersheds is projected to be higher than quality measured downstream. Maintaining water quality levels that will not foreclose water use options of downstream users will represent the key challenge to forest and range managers in the 21st century.

WETLANDS SUPPLY TRENDS[9]

The use of wetlands—the marshes, tundra, swamps, bogs, and bottomlands that comprise about 5% of the contiguous United States and about 60% of Alaska—is a source of controversy. Some want to convert these areas to other uses while others want them left in their natural state. Some wetlands provide natural ecological services such as floodwater storage, erosion and sedimentation control, nutrient removal to improve water quality and support food chains, and habitat for wildlife and fish. Consequently, wetlands offer varied recreational, educational, and vocational opportunities.

Wetlands are usually characterized by emergent plants growing on soils periodically or normally saturated with water.[10] Wetlands occur along gradually sloping areas between uplands and deep-water environments such as rivers, or form in basins isolated from larger water bodies. Of the 90 million acres of vegetated wetlands in the contiguous U.S., 95% are located in inland freshwater areas. The remainder are coastal saltwater environments. In addition, estimates are that nearly 60% of Alaska—over 200 million acres—is covered by wetlands.[11]

WETLANDS CONVERSION RATES AND ACTIVITIES RESPONSIBLE

Within the past 200 years, 30 to 50% of wetlands in the contiguous U.S. were converted to uses such as agriculture, mining, forestry, oil and gas extraction, and urbanization. According to the most recent federal survey, 11 million acres of wetlands in the lower 48 states were converted (the net change) to other uses between the mid-1950s and mid-1970s. This amount was equivalent to a net loss each year of 550,000 acres, or about 0.5% of remaining wetlands. Eighty percent of actual losses were due to draining and clearing wetlands for agriculture. Although some losses were due to natural events such as erosion, sedimentation, or subsidence, at least 95% of actual wetlands losses between 1960 and 1985 were due to human activities.

The current annual rate of wetlands loss is about 300,000 acres annually. A decline from the 550,000-acre rate of the 1950s to 1970s is due primarily to declining rates of agricultural drainage, and secondarily to government programs that regulate wetlands use. The U.S. Army Corps of Engineers' program under Section 404 of the Clean Water Act regulates many activities that involve disposal of dredge or fill material. Prior to this legislation, much of this material was used to fill wetlands. While coastal wetlands are protected reasonably well by a combination of federal and state regulatory programs, inland wetlands, which comprise 95% of the Nation's wetlands, are poorly protected.

Wetland conversion rates and activities vary significantly throughout the country. For example, conversions in the Lower Mississippi water resource region occurred at rates three times the national average from the mid-1950s to mid-1970s. In contrast, conversion rates along the Atlantic coast (excluding Florida) were only 30% of the national average. Overall, wetland conversions occurred in coastal areas at rates that were 25% less than inland conversion rates during the two-decade period.

From the mid-1950s to mid-1970s, 97% of actual wetlands losses occurred in inland freshwater areas. Agricultural conversions involving drainage, clearing, land leveling, groundwater pumping and surface water diversions were responsible for 80% of the conversions. Of the remainder, 8% resulted from construction of large impoundments and reservoirs, 6% from urbanization, and 6% from activities such as mining, forestry, and road construction. Fifty-three percent of inland wetlands conversions occurred in forested areas that were mainly bottomlands.

Of actual losses to coastal wetlands, 56% resulted from dredging marinas, canals, port developments, and to a lesser extent, from erosion. Urbanization accounted for 22% of the losses and 14% were due to disposal of dredge spoil or beach creation. The balance of the losses were due to natural or human-induced transition from saltwater to freshwater wetlands (6%) and agriculture (2%).

PROJECTED FUTURE LOSSES

Agriculture is the leading cause of wetlands losses (fig. 39 and table 15). If these losses are ignored, losses from all the other land uses balance the gains in wetlands from all land uses. Consequently, our wetlands future is inextricably linked to projected changes in agriculture.

The Appraisal (USDA 1987) concluded that remaining wetlands need protection. Nearly half of remaining nonfederal wetlands and almost all palustrine wetlands in the United States are potentially subject to conversion for agriculture. The 1982 Natural Resource Inventory reported the acreage of wet soils and wetlands that have "potential for conversion" based on similar lands converted in prior years.

About 5.2 million acres of wetlands have high or medium potential for conversion. Wetlands most likely to be drained and converted to agriculture fall into two

general categories: small wetland areas, either natural or manmade, that interfere with a farmer's agricultural operations; and relatively large areas in mature hardwood stands where timber values help offset land clearing costs, where land drainage and shaping costs are relatively low, where outlets for drainage water are readily available, and where there is continued profitable land ownership. Although some wetlands were converted directly to agricultural uses, about half were originally forested and entered agriculture use after being cut for timber.

The Food Security Act of 1985 (Public Law 99–447) contains a "swampbuster" provision that makes farmers ineligible for certain USDA programs if they convert wetlands. The Act provides for restrictions or prohibitions on federal commodity payments and loans to farmers who produce crops on newly converted wetlands. The Fish and Wildlife Service (FWS) and SCS have

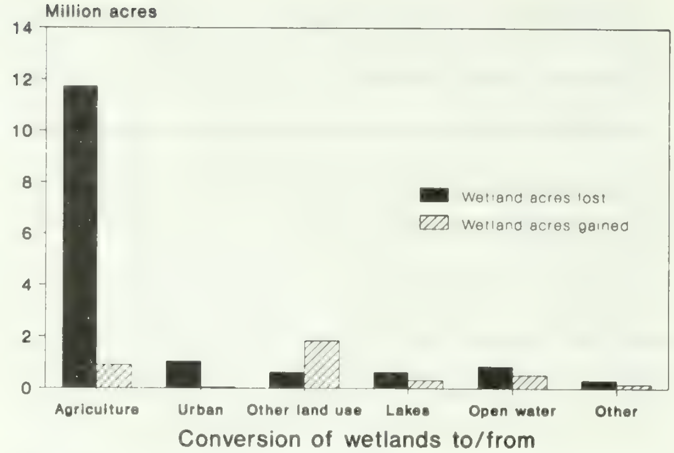

Figure 39.—Trends in the conversion of freshwater and saltwater wetlands, mid-1950s to mid-1970s (OTA 1984).

Table 15—Agricultural conversions of wetlands from the mid-1950s to mid-1970s

How accomplished	Important regions/ wetlands types	Reasons	Trend
Major drainage, flooding	Prairie potholes of Minnesota, North Dakota, South Dakota/ shallow, moderately deep marshes and seasonally flooded flats	Opportunity to gain additional cropland Elimination of nuisance potholes within cropland. Change in farming from diversified crops and livestock to row crops and small grain Increase in tractor horsepower Increases avoidance costs Increase in center-pivot irrigation Climatic variations Absence of financial incentives to maintain wetlands Drainage opportunities from channel projects and rural roads ditches Tax benefits for drainage	Of original, 25% to 30% of acres remain; greatest percentage and acreage drained in Minnesota. However, this is extremely variable within region, varying by 12% to 95%. Continuing conversion. Annual drainage rates estimates range from 0.1 to 5.0%. Almost half remaining wetlands are under protective programs; of these, 90% are permanent forms
Major drainage, flooding, excavation, land-leveling	Nebraska Rainwater Basin/shallow, moderately deep marshes and seasonally flooded flats	Intensify or expand cropland Drainage opportunities through rural road upgrading and improvement Drought incidence Possible federal or state cost-sharing assistance for reuse systems or leveling associated with irrigation Tax benefits for drainage Available farm equipment	Continuing conversion. Remaining are 15% to 25% original acres and 10% to 15% original basins. Protection programs cover 50% to 85% of remaining acreage. Nearly 90% of these are in permanent forms
Ground water pumping, associated land-leveling and filling	Nebraska Sandhills/wet meadows	Conversion of rangeland to cropland Long-term reduction in ground water levels and seasonal ground water variations due to expanding center-pivot irrigation Increase efficiency of center pivot Expand hay production into wetter areas	Accelerating conversion rate in last 10 years. Remaining are 85% to 95% of original acres and more than 95% of original basins
Ground water pumping, surface water diversions	Nebraska-Central Platte Valley/wet meadows	Indirect impact of regional irrigation development Conversion of rangelands to cropland	Of original wet meadows, 30% to 45% remaining
	California-Klamath Basin/emergent marshes	Conversion of rangeland to cropland	Of original acreage, 40% remaining. Continuing conversions on private and managed wetlands. Approximately 50% of remaining wetland and lake areas in national wildlife refuges and state wildlife management areas

Table 15—Agricultural conversions of wetlands from the mid-1950s to mid-1970s—Continued

How accomplished	Important regions/ wetlands types	Reasons	Trend
Normal farming: land-leveling of flood-irrigated areas, shift in crops, shift in planting and harvest schedules	California-Central Valley/emergent marshes	Less water available Increased pumping costs Clean farming practices Pesticide/herbicide use Flood control Irrigation technology	More than 90% converted from 1850 to 1978. Continuing conversions of ricelands to less water-intensive crops. Degradation of habitat on secondary wetland areas. Of remaining acreage, 20% in public ownership)
Drainage, land-leveling	California-Central Valley/emergent marshes	Less water available Higher taxes on nonagricultural lands Increased pumping costs Degradation of habitat on secondary wetland areas	See above description of overall trends of Central Valley. Conversion of private wetlands to agriculture. Reduction of flooded public acreage
Clearing vegetation	Lower Mississippi River Valley/ bottom land hardwoods	Soybeans demand Relative price of timber Drought incidence Flood-control projects	Significant conversion prior to 1937. Forty-four percent reduction, 1937–1977. Forest remaining 0% to more than 60% (1979). Rate of clearing peaked 1967 (except Louisana). Clearing rates related to forest left. Continuing conversion
Clearing vegetation drainage	North and South Carolina/bottom land hardwoods	Relative price of timber Improved drainage equipment Refined use of lime, fertilizer, pesticides Improve seed stocks Agribusiness investment	Increase from 1930's to 1950's from reforestation of abandoned farms. Increasing rate of conversion 1950s to 1970s
Clearing vegetation, drainage	North Carolina/pocosins	Improved drainage equipment	By 1979, 33% totally developed. Of remaining areas, 65% owned by agricultural and forest products industries. Five percent protected from drainage through public ownership or lease
Clearing vegetation, drainage	South Carolina/carolina bays	Large-scale agriculture Forestry	Ninety-five percent altered
Clearing vegetation, drainage	South Florida/cypress	Agricultural and urban uses	Conversions occurred from 1900 to 1973, including 25% of cypress domes and stands and 12% of scrub cypress. Continuing conversions
Lack of drainage, ditch maintenance	New England/wooded wetlands	Agricultural abandonment	Wetlands recreated
Mowing, seeding, fertilizing, grazing	South Florida/wet prairies, sawgrass	Expanded agriculture Transform areas to dry land to prepare for urban development (and avoid regulations associated with fill in wetalands)	Conversion of 45% to 52% of wetlands from 1900 to 1973. Continuing conversions

Source: OTA (1984)

cooperated to define the vegetation and soil types characterizing wetlands eligible for protection under this program.

There are 17 million acres of wetlands having some potential for crop production. Heimlich (1988) concluded that the swampbuster provision will likely hamper conversion on only about one-third of these acres—the 5.2 million acres with medium to high crop production potential. Nearly half of the 5.2 million acres are in the South and 30% are in the North. Wetlands conversion in much of the South Atlantic-Gulf region will likely *not* be affected by withholding of farm program benefits according to Heimlich's analysis. Additional information on the swampbuster provision is found in Heimlich and Langner (1986).

While the Corps' Section 404 program and swampbuster provisions of the Food Security Act discourage conversion of wetlands, other laws and regulations exist that subsidize wetlands conversions. For example, the federal income tax law (and many states' income tax

laws) authorize tax credits for investments, deductions for expenses of operations, and special provisions for resource depletions. Conversion of wetlands has historically been judged an investment with costs eligible for special treatment when income taxes are computed.

Local property taxation administration also favors conversion in some areas. For example, OTA (1984) cited the case of a hunting club in California that owned a large parcel of wetlands. When the recorded land use was changed to recreational land from wetlands, the increased tax burden made it difficult to maintain the club. Financial problems brought on by increased assessed values can lead to sales to developers, making conversion more imminent. Many local governments provide property tax breaks where the assessed value is dependent upon land use; this encourages landowners to keep land in forest cover. Similar local property tax relief would be useful to help preserve wetlands.

OTHER WETLANDS USES AFFECTED BY CONVERSIONS

Wetlands provide food and habitat for many game and non-game animals. For some species, wetlands are essential for survival. For example, waterfowl require wetlands for breeding and nesting. These birds nest primarily in northern freshwater wetlands in the U.S. and Canada in the spring and summer, but use wetlands for feeding and cover in all parts of the country during migration and overwintering. Survival, return, and successful breeding of many species, therefore, depends on a wide variety of wetland types throughout North America. It is no coincidence that major migratory routes, breeding and nesting areas, and overwintering areas correspond with regions of greatest wetland concentrations, and that waterfowl populations have declined along with the decline in wetlands acreage.

For other species, wetlands serve more general needs. Coastal marshes and certain types of inland freshwater wetlands achieve some of the highest rates of plant productivity of any natural ecosystem. This high productivity often supports varied and abundant animal populations within a complex food chain. During the growing season, less than 15% of the plant biomass in saltwater marshes is consumed directly by foraging animals. After plants die, up to 70% of the plant material disintegrates into small particles and is flushed into adjacent water where it becomes a potent food source for estuarine-dependent fish and shellfish.

Several fish species are dependent upon wetlands, as they prefer to spawn in shallow, vegetated water. Wetlands afford abundant food for fingerlings and existing vegetation offers protection from currents, sunlight, and predators.

Wetlands are home to wildlife of economic importance including minks, muskrats, and nutria (furbearers); alligators (hides and meat); and crayfish and assorted fish and shellfish (meat). Other plants and animals could become equally important if proven to be sources of food, chemicals, or extracts.

Other important functions of wetlands include shoreline stabilization, groundwater recharge, and recreation. Vegetated freshwater wetlands significantly reduce shoreline erosion caused by large waves and major coastal riverain flooding. Some wetlands hydrologically connected to groundwater systems provide aquifer recharge through infiltration and percolation of surface water. In general, recharge rates in uplands are typically higher than for wetlands. Finally, because of the habitat wetlands provide for fish and wildlife, they are prime recreation areas for wildlife observation and nature photography, as well as hunting and fishing.

The wildlife and fish assessment that is part of this Assessment provides additional information on wetlands and their importance.

SUMMARY

The historic rate of wetlands conversion of the mid-1950s to mid-1970s (550,000 acres annually) dropped to 300,000 acres in the mid-1980s. Nearly half the land converted during this period was forested palustrine wetlands. The predominant reason for converting wetlands has been to provide additional agricultural acreage.

About 5.2 million acres of wetlands are potentially suitable for conversion to agriculture. Recent changes in agricultural policy will preclude significant additional conversions of these wetlands, particularly forested ones, to agricultural use. The rate of wetlands conversion to agriculture is expected to dip significantly as swampbuster provisions take effect. By the year 2000, conversions are projected to be around 100,000 acres annually. Whether there is any further dip in the conversion rate will depend on whether additional disincentives can be created for conversion to non-agricultural land uses. There remain 11.8 million acres of wetlands only marginally suitable for agriculture that may still move easily into non-agricultural land uses unaffected by the swampbuster provision.

Wetlands support a rich and diversified population of plants and animals, many having economic importance. Further, wetlands provide considerable recreation opportunity and other benefits, such as erosion control. The continuing conversion process chips away at wetlands benefits resulting in losses to society that cannot be adequately compensated.

The acreage of wetlands on federal lands will remain at current levels throughout the planning period due to increased sensitivity to ecological, economic, and social values of wetlands. On private lands, acreage will continue to decrease, but at a slower pace through 2020. The net result by 2020 will be about 94 million acres of wetlands, an area that stays constant to 2040.

NOTES

1. A "stock" resource is one whose supply is fixed or set at the beginning of the planning period. The quantity available cannot be increased, but use can decrease the amount.

2. Managers have no method capable of making significant regional or national increases in water supplies. Cloud seeding, where it has been successful, has only affected specific localities at intermittent intervals.

3. This section is taken largely from Tennant (1975) and first appeared in the water chapter of the 1979 RPA Assessment (USDA Forest Service 1981).

4. USDA (1987) concluded that the trend in damages is increasing at an annual rate of $30.0 million (1984 dollars).

5. This section is drawn largely from USDA Forest Service (1981) and the EPA (1987).

6. STORET is an acronym for the U.S. Environmental Protection Agency's water quality data storage and retrieval program.

7. The numbers in table 13 do not necessarily represent an "average" water quality. Levels of these constituents are a function of the time of day as well as flow characteristics. The quality samples are usually collected during day time and during non-storm periods, so diurnal variation and water quality effects of storm flows are not well represented in this data.

8. EPA (1987, table 5.4). The totals are in 1982 constant dollars.

9. This section is drawn largely from U.S. Congress (1984).

10. This Assessment adopts a wetlands definition following the one employed by the Fish and Wildlife Service of the U.S. Department of the Interior for mapping and land classification. There is a second, and more restrictive, definition of wetlands employed by federal agencies—principally the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency—for the purpose of regulation. Under the former definition, there were 99 million acres of wetlands in the contiguous U.S. in the mid-1970s. Using the latter definition, there were only 64 million acres of wetlands. For example, under the definition used here, the drier sections of bottomland hardwood sites are included as wetland but the Corps of Engineers does not exercise regulatory control over these areas. The differences in definition led to considerable confusion because the public often views the federal government as monolithic and does not differentiate between the different purposes behind the two definitions.

11. The frozen tundra is another example of a site that meets the Fish and Wildlife Service's definition of wetland—soils that are periodically or normally saturated with water—albeit frozen water. The Corps of Engineers and Environmental Protection agency ignore such sites for purposes of regulating wetlands use.

CHAPTER 5: COMPARISON OF PROJECTED DEMAND AND SUPPLY SITUATIONS

PLENTIFUL SUPPLIES AND SHORTAGES

The generalized water balance by water resource region was introduced in table 2 to illustrate the current water use situation. The surplus/deficit column indicated how much water is available in the year of mean precipitation for offstream water uses. The water balance was extended in table 12 to account for variations in precipitation between average and two lower levels of precipitation—the 80% level expected to be exceeded 4 years in 5 and the 95% level expected to be exceeded 19 years in 20.

The comparison of projected supplies and demands is presented in this chapter through use of the most complete form of the generalized water balance approach (table 16). Offstream consumptive uses from 1985 to 2040—the demand projections—are incorporated in this table. The surplus/deficit column shows where supplies are expected to be plentiful throughout the next five decades and where shortages are expected.

It is important to note that table 16 presents a comparison where two variables play key roles because they are linked and each is only allowed to be in one of two states. The two variables are rainfall condition and instream flow requirements. Rainfall condition is either "average" (the mean expectation) or "dry" (the 80% level). Instream flow conditions are linked to the rainfall situation. Instream flow providing optimal fish and wildlife habitat is paired with the average rainfall expectation. Instream flow providing good survival habitat is paired with the dry rainfall condition (80% expectation). In essence, this pairing produces surpluses/deficits that bracket a continuum where flows are likely to occur. Thus, it is possible that the surplus in an average rainfall year is less than that in a dry year because of an accompanying shift in instream flow assumptions from optimal to good survival habitat. Moreover, where deficits occur, the implication is that one or more assumptions inherent in the water balance are being violated. The most obvious one is the instream flow requirement. Deficits typically imply that less than the assumed habitat is being provided. For the dry condition, deficits infer that poor survival habitat is provided. The assumption second most likely to be violated is the groundwater overdraft situation. Deficits imply that the overdraft is higher (worse) than estimated.

Deficits identified in table 16 result from a number of factors, including climatological, physiographical, edaphic, economic, technological, and institutional. When an insufficient quantity of water is available for use due to economic, technological, or institutional factors, a *shortage* exists. When an insufficient quantity of water is available for use due to climatological, physiographical, or edaphic factors, a *scarcity* exists. Deficits in table 16 are referred to as shortages throughout the chapter because the prevailing price and institutional frameworks for water use are assumed constant throughout the projection period.

Concern over sufficiency of instream flows for fish and wildlife habitat and recreation will provide the primary impetus for resolving projected water supply deficits.

Table 16.—Generalized water budget for average and dry years, 1985-2040, by water resources region[1]

Water resource region	Rainfall condition[2]	Renewable water supply[3]	Ground-water overdraft[4]	Imports or exports[5]	Reservoir net evaporation[6]	Offstream consumptive use[7] Agriculture	Offstream consumptive use[7] Non-agriculture	Average stream outflow[8]	Instream flow requirement[9]	Surplus or deficit[10]
New England	1985 avg.	77.30	0.00	0.00	0.20	0.06	0.70	76.35	69.00	7.35
	2000 avg.	77.30	0.00	0.00	0.20	0.06	1.05	75.99	69.00	6.99
	2000 dry	62.15	0.00	0.00	0.20	0.07	1.05	60.83	46.40	14.43
	2010 avg.	77.30	0.00	0.00	0.20	0.06	1.18	75.86	69.00	6.86
	2010 dry	62.15	0.00	0.00	0.20	0.07	1.18	60.69	46.40	14.29
	2020 avg.	77.30	0.00	0.00	0.20	0.06	1.29	75.75	69.00	6.75
	2020 dry	62.15	0.00	0.00	0.20	0.08	1.29	60.58	46.40	14.18
	2030 avg.	77.30	0.00	0.00	0.20	0.07	1.40	75.63	69.00	6.63
	2030 dry	62.15	0.00	0.00	0.20	0.08	1.40	61.34	46.40	14.94
	2040 avg.	77.30	0.00	0.00	0.20	0.07	1.50	75.53	69.00	6.53
	2040 dry	62.15	0.00	0.00	0.20	0.08	1.50	60.37	46.40	13.97
Mid-Atlantic	1985 avg.	96.50	0.00	-0.70	0.20	0.31	1.47	93.82	68.84	24.98
	2000 avg.	96.50	0.00	-0.70	0.20	0.36	2.24	93.00	68.84	24.16
	2000 dry	75.03	0.00	-0.70	0.20	0.43	2.24	71.46	57.90	13.56
	2010 avg.	96.50	0.00	-0.70	0.20	0.37	2.55	92.68	68.84	23.84
	2010 dry	75.03	0.00	-0.70	0.20	0.45	2.55	71.13	57.90	13.23
	2020 avg.	96.50	0.00	-0.70	0.20	0.39	2.82	92.39	68.84	23.55
	2020 dry	75.03	0.00	-0.70	0.20	0.46	2.82	70.84	57.90	12.94
	2030 avg.	96.50	0.00	-0.70	0.20	0.40	3.09	92.11	68.84	23.27
	2030 dry	75.03	0.00	-0.70	0.20	0.48	3.09	70.56	57.90	12.66
	2040 avg.	96.50	0.00	-0.70	0.20	0.41	3.38	91.81	68.84	22.97
	2040 dry	75.03	0.00	-0.70	0.20	0.49	3.38	70.26	57.90	12.36
South Atlantic-Gulf	1985 avg.	213.00	0.00	0.00	0.50	2.93	2.32	207.25	188.70	18.55
	2000 avg.	213.00	0.00	0.00	0.50	3.43	3.34	205.73	188.70	17.03
	2000 dry	154.51	0.00	0.00	0.50	4.11	3.34	146.56	127.81	18.75
	2010 avg.	213.00	0.00	0.00	0.50	3.58	3.74	205.18	188.70	16.48
	2010 dry	154.51	0.00	0.00	0.50	4.30	3.74	145.97	127.81	18.16
	2020 avg.	213.00	0.00	0.00	0.50	3.73	4.10	204.67	188.70	15.97
	2020 dry	154.51	0.00	0.00	0.50	4.48	4.10	145.43	127.81	17.62
	2030 avg.	213.00	0.00	0.00	0.50	3.85	4.46	204.19	188.70	15.49
	2030 dry	154.51	0.00	0.00	0.50	4.62	4.46	144.93	127.81	17.12
	2040 avg.	213.00	0.00	0.00	0.50	3.96	4.82	203.72	188.70	15.02
	2040 dry	154.51	0.00	0.00	0.50	4.75	4.82	144.44	127.81	16.63
Great Lakes	1985 avg.	76.80	0.00	-1.30	0.30	0.34	1.88	72.98	63.95	9.03
	2000 avg.	76.80	0.00	-1.30	0.30	0.39	3.11	71.70	63.95	7.75
	2000 dry	61.09	0.00	-1.30	0.30	0.47	3.11	55.91	46.08	9.83
	2010 avg.	76.80	0.00	-1.30	0.30	0.41	3.63	71.16	63.95	7.21
	2010 dry	61.09	0.00	-1.30	0.30	0.49	3.63	55.37	46.08	9.29
	2020 avg.	76.80	0.00	-1.30	0.30	0.43	4.06	70.71	63.95	6.76
	2020 dry	61.09	0.00	-1.30	0.30	0.51	4.06	54.92	46.08	8.84
	2030 avg.	76.80	0.00	-1.30	0.30	0.44	4.56	70.20	63.95	6.25
	2030 dry	61.09	0.00	-1.30	0.30	0.53	4.56	54.40	46.08	8.32
	2040 avg.	76.80	0.00	-1.30	0.30	0.45	5.15	69.60	63.95	5.65
	2040 dry	61.09	0.00	-1.30	0.30	0.54	5.15	53.80	46.08	7.72
Ohio[11]	1985 avg.	140.00	0.00	0.00	0.40	0.19	2.03	137.38	122.00	15.38
	2000 avg.	140.00	0.00	0.00	0.40	0.20	3.25	136.15	122.00	14.15
	2000 dry	107.67	0.00	0.00	0.40	0.24	3.25	103.79	84.00	19.79
	2010 avg.	140.00	0.00	0.00	0.40	0.21	3.77	135.62	122.00	13.62
	2010 dry	107.67	0.00	0.00	0.40	0.25	3.77	103.26	84.00	19.26
	2020 avg.	140.00	0.00	0.00	0.40	0.22	4.20	135.18	122.00	13.18
	2020 dry	107.67	0.00	0.00	0.40	0.26	4.20	102.81	84.00	18.81
	2030 avg.	140.00	0.00	0.00	0.40	0.22	4.71	134.67	122.00	12.67
	2030 dry	107.67	0.00	0.00	0.40	0.27	4.71	102.30	84.00	18.30
	2040 avg.	140.00	0.00	0.00	0.40	0.23	5.29	134.08	122.00	12.08
	2040 dry	107.67	0.00	0.00	0.40	0.27	5.29	101.71	84.00	17.71
Tennessee	1985 avg.	43.30	0.00	0.00	0.00	0.04	0.33	42.93	38.48	4.45
	2000 avg.	43.30	0.00	0.00	0.00	0.04	0.50	42.76	38.48	4.28
	2000 dry	38.14	0.00	0.00	0.00	0.04	0.50	38.14	25.98	12.16
	2010 avg.	43.30	0.00	0.00	0.00	0.04	0.56	42.70	38.48	4.22
	2010 dry	38.14	0.00	0.00	0.00	0.05	0.56	37.54	25.98	11.56
	2020 avg.	43.30	0.00	0.00	0.00	0.04	0.62	42.64	38.48	4.16
	2020 dry	38.14	0.00	0.00	0.00	0.05	0.62	37.47	25.98	11.49
	2030 avg.	43.30	0.00	0.00	0.00	0.04	0.67	42.59	38.48	4.11
	2030 dry	38.14	0.00	0.00	0.00	0.05	0.67	37.42	25.98	11.44
	2040 avg.	43.30	0.00	0.00	0.00	0.04	0.73	42.53	38.48	4.05
	2040 dry	38.14	0.00	0.00	0.00	0.05	0.73	37.36	25.98	11.38
Upper Mississippi[12]	1985 avg.	79.90	0.00	2.00	0.60	0.62	1.21	79.47	69.70	9.77
	2000 avg.	79.90	0.00	2.00	0.60	0.69	1.81	78.80	69.70	9.10
	2000 dry	64.81	0.00	2.00	0.60	0.82	1.81	63.57	47.94	15.63
	2010 avg.	79.90	0.00	2.00	0.60	0.71	2.05	78.54	69.70	8.84
	2010 dry	64.81	0.00	2.00	0.60	0.86	2.05	63.30	47.94	15.36
	2020 avg.	79.90	0.00	2.00	0.60	0.75	2.25	78.30	69.70	8.60
	2020 dry	64.81	0.00	2.00	0.60	0.89	2.25	63.06	47.94	15.12
	2030 avg.	79.90	0.00	2.00	0.60	0.77	2.46	78.07	69.70	8.37
	2030 dry	64.81	0.00	2.00	0.60	0.92	2.46	62.82	47.94	14.88
	2040 avg.	79.90	0.00	2.00	0.60	0.79	2.67	77.84	69.70	8.14
	2040 dry	64.81	0.00	2.00	0.60	0.95	2.67	62.59	47.94	14.65
Lower Mississippi[13]	1985 avg.	470.00	5.80	0.00	6.00	24.99	5.88	377.06	359.00	18.06
	2000 avg.	470.00	5.37	0.00	6.90	29.37	8.98	369.78	359.00	10.78
	2000 dry	315.90	5.37	0.00	6.90	33.83	8.98	275.59	282.00	-6.41
	2010 avg.	470.00	5.08	0.00	7.50	30.69	10.26	366.93	359.00	7.93
	2010 dry	315.90	5.08	0.00	7.50	35.36	10.26	272.05	282.00	-9.95
	2020 avg.	470.00	4.79	0.00	8.10	31.98	11.34	364.26	359.00	5.26
	2020 dry	315.90	4.79	0.00	8.10	36.84	11.34	269.22	282.00	-12.78

Table 16.—Generalized water budget for average and dry years, 1985-2040, by water resources region[1]—Continued

	2030 avg.	470.00	4.50	0.00	8.70	32.99	12.52	355.16	359.00	-3.84
	2030 dry	315.90	4.50	0.00	8.70	38.00	12.52	258.68	282.00	-23.32
	2040 avg.	470.00	4.20	0.00	9.30	33.91	13.79	352.45	359.00	-6.55
	2040 dry	315.90	4.20	0.00	9.30	39.06	13.79	255.81	282.00	-26.19
Souris-Red-Rainy	1985 avg.	7.70	0.00	0.00	0.40	0.08	0.06	7.16	3.67	3.49
	2000 avg.	7.70	0.00	0.00	0.40	0.09	0.08	7.13	3.67	3.46
	2000 dry	4.38	0.00	0.00	0.40	0.11	0.08	3.79	2.31	1.48
	2010 avg.	7.70	0.00	0.00	0.40	0.09	0.09	7.12	3.67	3.45
	2010 dry	4.38	0.00	0.00	0.40	0.11	0.09	3.78	2.31	1.47
	2020 avg.	7.70	0.00	0.00	0.40	0.10	0.10	7.10	3.67	3.43
	2020 dry	4.38	0.00	0.00	0.40	0.11	0.10	3.77	2.31	1.46
	2030 avg.	7.70	0.00	0.00	0.40	0.10	0.10	7.10	3.67	3.43
	2030 dry	4.38	0.00	0.00	0.40	0.12	0.10	3.76	2.31	1.45
	2040 avg.	7.70	0.00	0.00	0.40	0.10	0.11	7.09	3.67	3.42
	2040 dry	4.38	0.00	0.00	0.40	0.12	0.11	3.75	2.31	1.44
Missouri	1985 ave.	67.30	2.20	0.20	3.30	11.96	0.88	53.56	33.96	19.60
	2000 avg.	67.30	2.20	0.17	4.07	14.11	1.26	50.23	33.96	16.27
	2000 dry	51.07	2.20	0.10	4.07	15.53	1.26	32.51	20.12	12.40
	2010 avg.	67.30	2.20	0.14	4.58	14.75	1.42	48.89	33.96	14.93
	2010 dry	51.07	2.20	0.03	4.58	16.23	1.42	31.08	20.12	10.96
	2020 avg.	67.30	2.20	0.12	5.09	15.37	1.55	47.61	33.96	13.65
	2020 dry	51.07	2.20	-0.03	5.09	16.91	1.55	29.69	20.12	9.57
	2030 avg.	67.30	2.20	0.10	5.60	15.86	1.68	46.46	33.96	12.50
	2030 dry	51.07	2.20	-0.10	5.60	17.44	1.68	28.45	20.19	8.26
	2040 avg.	67.30	2.20	0.08	6.11	16.30	1.81	45.36	33.96	11.40
	2040 dry	51.07	2.20	-0.17	6.11	17.93	1.81	27.25	20.19	7.06
Arkansas-White-Red	1985 avg.	63.70	3.60	0.10	1.40	7.43	0.66	57.91	46.17	11.74
	2000 avg.	63.70	3.17	0.13	1.50	8.77	0.95	55.78	46.17	9.61
	2000 dry	39.98	3.17	0.13	1.50	10.52	0.95	30.31	19.11	11.20
	2010 avg.	63.70	2.88	0.15	1.56	9.17	1.07	54.93	46.17	8.76
	2010 dry	39.98	2.88	0.15	1.56	11.00	1.07	29.38	19.11	10.27
	2020 avg.	63.70	2.59	0.17	1.63	9.55	1.18	54.10	46.17	7.93
	2020 dry	39.98	2.59	0.17	1.63	11.46	1.18	28.47	19.11	9.36
	2030 avg.	63.70	2.30	0.20	1.70	9.85	1.28	53.37	46.17	7.20
	2030 dry	39.98	2.30	0.20	1.70	11.82	1.28	27.68	19.11	8.57
	2040 avg.	63.70	2.00	0.22	1.77	10.13	1.38	52.64	46.17	6.47
	2040 dry	39.98	2.00	0.22	1.77	12.16	1.38	26.90	19.11	7.79
Texas-Gulf	1985 avg.	35.90	3.10	0.00	1.80	4.57	1.54	31.09	22.92	8.17
	2000 avg.	35.90	3.10	0.00	1.87	5.38	2.29	29.46	22.92	6.54
	2000 dry	19.77	3.10	0.00	1.87	5.92	2.29	12.80	10.77	2.03
	2010 avg.	35.90	3.10	0.00	1.91	5.62	2.57	28.90	22.92	5.98
	2010 dry	19.77	3.10	0.00	1.91	6.19	2.57	12.21	10.77	1.44
	2020 avg.	35.90	3.10	0.00	1.96	5.86	2.82	28.36	22.92	5.44
	2020 dry	19.77	3.10	0.00	1.96	6.44	2.82	11.65	10.77	0.88
	2030 avg.	35.90	3.10	0.00	2.00	6.04	3.05	27.91	22.92	4.99
	2030 dry	19.77	3.10	0.00	2.00	6.65	3.05	11.18	10.77	0.41
	2040 avg.	35.90	3.10	0.00	2.04	6.21	3.26	27.49	22.92	4.57
	2040 dry	19.77	3.10	0.00	2.04	6.83	3.26	10.74	10.77	-0.03
Rio Grande	1985 avg.	5.00	0.00	0.10	0.80	2.01	0.22	2.07	2.29	-0.22
	2000 avg.	5.00	0.00	0.10	0.80	2.37	0.32	1.61	2.29	-0.68
	2000 dry	4.09	0.00	0.10	0.80	2.61	0.32	0.46	1.50	-1.04
	2010 avg.	5.00	0.00	0.10	0.80	2.48	0.36	1.46	2.29	-0.83
	2010 dry	4.09	0.00	0.10	0.80	2.73	0.36	0.30	1.50	-1.20
	2020 avg.	5.00	0.00	0.10	0.80	2.59	0.39	1.32	2.29	-0.97
	2020 dry	4.09	0.00	0.10	0.80	2.84	0.39	0.16	1.50	-1.34
	2030 avg.	5.00	0.00	0.10	0.80	2.67	0.42	1.21	2.29	-1.08
	2030 dry	4.09	0.00	0.10	0.80	2.93	0.42	0.04	1.50	-1.46
	2040 avg.	5.00	0.00	0.10	0.80	2.74	0.44	1.12	2.29	-1.17
	2040 dry	4.09	0.00	0.10	0.80	3.02	0.44	-0.07	1.50	-1.57
Upper Colorado	1985 avg.	12.30	0.00	-0.60	1.70	2.23	0.17	7.60	7.95	-0.35
	2000 avg.	12.30	0.00	-0.70	1.70	2.64	0.28	6.98	7.95	-0.97
	2000 dry	9.67	0.00	-0.70	1.70	2.91	0.28	4.08	3.69	0.39
	2010 avg.	12.30	0.00	-0.77	1.70	2.77	0.33	6.73	7.95	-1.22
	2010 dry	9.67	0.00	-0.77	1.70	3.04	0.33	3.83	3.69	0.14
	2020 avg.	12.30	0.00	-0.83	1.70	2.88	0.37	6.52	7.95	-1.43
	2020 dry	9.67	0.00	-0.83	1.70	3.17	0.37	3.60	3.69	-0.09
	2030 avg.	12.30	0.00	-0.90	1.70	2.97	0.42	6.31	7.95	-1.64
	2030 dry	9.67	0.00	-0.90	1.70	3.27	0.42	3.38	3.69	-0.31
	2040 avg.	12.30	0.00	-0.97	1.70	3.06	0.47	6.11	7.95	-1.84
	2040 dry	9.67	0.00	-0.97	1.70	3.36	0.47	3.17	3.69	-0.52
Lower Colorado[14]	1985 avg.	11.20	2.10	-3.70	3.60	5.86	0.80	-0.66	6.86	-7.52
	2000 avg.	11.20	2.10	-3.60	3.60	6.94	1.21	-2.05	6.86	-8.91
	2000 dry	8.79	2.10	-3.60	3.60	7.63	1.21	-5.15	3.36	-8.51
	2010 avg.	11.20	2.10	-3.53	3.60	7.25	1.63	-2.72	6.86	-9.58
	2010 dry	8.79	2.10	-3.53	3.60	7.98	1.63	-5.85	3.36	-9.21
	2020 avg.	11.20	2.10	-3.47	3.60	7.56	1.50	-2.82	6.86	-9.68
	2020 dry	8.79	2.10	-3.47	3.60	8.31	1.50	-5.99	3.36	-9.35
	2030 avg.	11.20	2.10	-3.40	3.60	7.80	1.62	-3.12	6.86	-9.98
	2030 dry	8.79	2.10	-3.40	3.60	8.58	1.62	-6.30	3.36	-9.66

Table 16.—Generalized water budget for average and dry years, 1985-2040, by water resources region[1]—Continued

	2040 avg.	11.20	2.10	-3.32	3.60	8.02	1.75	-3.38	6.86	-10.24
	2040 dry	8.79	2.10	-3.32	3.60	8.82	1.75	-6.59	3.36	-9.95
Great Basin	1985 avg.	8.30	0.00	0.00	0.20	3.39	0.23	4.49	3.39	1.10
	2000 avg.	8.30	0.00	0.00	0.20	4.01	0.33	3.76	3.39	0.37
	2000 dry	7.02	0.00	0.00	0.20	4.41	0.33	2.08	2.49	-0.41
	2010 avg.	8.30	0.00	0.00	0.20	4.19	0.36	3.54	3.39	0.15
	2010 dry	7.02	0.00	0.00	0.20	4.61	0.36	1.85	2.49	-0.64
	2020 avg.	8.30	0.00	0.00	0.20	4.37	0.40	3.34	3.39	-0.05
	2020 dry	7.02	0.00	0.00	0.20	4.81	0.40	1.62	2.49	-0.87
	2030 avg.	8.30	0.00	0.00	0.20	4.51	0.42	3.17	3.39	-0.22
	2030 dry	7.02	0.00	0.00	0.20	4.96	0.42	1.45	2.49	-1.04
	2040 avg.	8.30	0.00	0.00	0.20	4.63	0.44	3.03	3.39	-0.36
	2040 dry	7.02	0.00	0.00	0.20	5.10	0.44	1.29	2.49	-1.20
Pacific Northwest	1985 avg.	291.00	0.00	0.00	0.60	12.15	0.59	277.67	214.00	63.67
	2000 avg.	291.00	0.00	0.00	0.60	14.38	0.74	275.29	214.00	61.29
	2000 dry	245.52	0.00	0.00	0.60	17.25	0.74	226.93	174.60	52.33
	2010 avg.	291.00	0.00	0.00	0.60	15.03	0.81	274.56	214.00	60.56
	2010 dry	245.52	0.00	0.00	0.60	18.03	0.81	226.07	174.60	51.47
	2020 avg.	291.00	0.00	0.00	0.60	15.66	0.87	273.87	214.00	59.87
	2020 dry	245.52	0.00	0.00	0.60	18.79	0.87	225.26	174.60	50.66
	2030 avg.	291.00	0.00	0.00	0.60	16.15	0.93	273.32	214.00	59.32
	2030 dry	245.52	0.00	0.00	0.60	19.38	0.93	224.61	174.60	50.01
	2040 avg.	291.00	0.00	0.00	0.60	16.61	0.98	272.82	214.00	58.82
	2040 dry	245.52	0.00	0.00	0.60	19.93	0.98	224.01	174.60	49.41
California	1985 avg.	86.90	1.40	3.70	0.50	19.36	1.70	70.44	32.61	37.83
	2000 avg.	86.90	1.22	3.60	0.50	22.92	2.45	65.85	32.61	33.24
	2000 dry	42.72	1.22	3.60	0.50	25.21	2.45	19.38	26.07	-6.69
	2010 avg.	86.90	1.10	3.53	0.50	23.96	2.72	64.35	32.61	31.74
	2010 dry	42.72	1.10	3.53	0.50	26.36	2.72	17.77	26.07	-8.30
	2020 avg.	86.90	0.98	3.47	0.50	24.96	2.96	62.93	32.61	30.32
	2020 dry	42.72	0.98	3.47	0.50	27.46	2.96	16.26	26.07	-9.81
	2030 avg.	86.90	0.86	3.40	0.50	25.75	3.15	61.77	32.61	29.16
	2030 dry	42.72	0.86	3.40	0.50	28.32	3.15	15.01	26.07	-11.06
	2040 avg.	86.90	0.74	3.32	0.50	26.48	3.29	60.69	32.61	28.08
	2040 dry	42.72	0.74	3.32	0.50	29.13	3.29	13.86	26.07	-12.21
Total contiguous U.S.[15]	1985 avg.	1379.60	12.40	-1.90	15.10	76.03	17.38	1281.59	1043.18	238.41
	2000 avg.	1379.60	11.79	-1.90	16.07	89.69	26.14	1257.60	1043.18	214.42
	2000 dry	1000.98	11.79	-1.90	16.07	102.05	26.14	866.61	784.98	81.63
	2010 avg.	1379.60	11.38	-1.90	16.71	93.75	29.90	1248.71	1043.18	205.53
	2010 dry	1000.98	11.38	-1.90	16.71	106.67	29.90	857.18	784.98	72.20
	2020 avg.	1379.60	10.97	-1.90	17.36	97.68	32.64	1241.00	1043.18	197.82
	2020 dry	1000.98	10.97	-1.90	17.36	111.14	32.64	848.91	784.98	63.93
	2030 avg.	1379.60	10.56	-1.90	18.00	100.75	35.72	1233.79	1031.03	202.76
	2030 dry	1000.98	10.56	-1.90	18.00	114.64	35.71	841.29	784.98	56.31
	2040 avg.	1379.60	10.14	-1.90	18.64	103.59	38.90	1226.70	1043.18	183.52
	2040 dry	1000.98	10.14	-1.90	18.64	117.87	38.90	833.81	784.98	48.83

[1] *The figures in this table differ from those in the Appraisal (USDA 1987, table 16-2) because new projections of offstream consumptive use were prepared for this report based upon regression analyses and more recent water use and demographic data. For example, the 1985 estimates of water use from the Geological Survey were available for this report but not for the Appraisal. Also, the Appraisal was based upon 1982 projections of population and economic growth, this report used 1987 projections.*

[2] *Average condition represents the flows in a "normalized" year, when the amount of annual precipitation is the long-term average (the precipitation that is exceeded 50 percent of the time). The dry condition is the normalized flow when the amount of annual precipitation is exceeded 80 percent of the time.*

[3] *Renewable supply is the precipitation that reaches aquifers or that runs off into surface water supplies. It is estimated by taking measured 1985 instream flows, subtracting other supplies (overdrafts and imports), and adding depletions (consumptive use, net reservoir evaporation, and exports).*

[4] *Groundwater overdrafts are quantities of water withdrawn from aquifers in excess of the recharge volume. These estimates were obtained from Anon. (1984, page 243), cited by Foxworthy and Moody (1986, table 7).*

[5] *Exports are shown in the table as a negative number. The data were taken from Petch (1985), cited by Foxworthy and Moody (1986, table 8).*

[6] *Data for net reservoir evaporation were taken from Foxworthy and Moody (1986, table 7).*

[7] *Consumptive use estimates for agriculture are the sum of numbers in tables A-14 and A-18. Consumptive use estimates for non-agriculture are the sum of numbers from tables A-13, A-15, A-16, and A-17. All the estimates for 2000 to 2040 are new projections prepared for this report. Dry year agricultural use is 20% higher in humid regions, 10% higher in dry regions (Flickinger 1988).*

[8] *Average stream outflow for 1985 is from Graczyk and others (1986). Outflows are computed for 2000 to 2040 from renewable supply.*

[9] *Instream flow requirements for average years are the flows needed for optimal fish and wildlife habitat. Data are from Water Resources Council (1978). Instream flow requirements for good survival habitat in dry years are assumed to be 60% of mean natural flow in the average year for New England, MidAtlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee, Upper and Lower Mississippi and the Pacific Northwest regions. In the other regions, the instream flow requirements for good survival habitat in dry years are assumed to be 30% of mean natural flow in the average year (Flickinger 1987).*

[10] *A surplus exists if the average stream outflow exceeds the instream flow requirement. A deficit exists if the instream flow requirement exceeds the average stream outflow.*

[11] *The estimates for the Ohio water resource region are exclusive of outflows from the Tennessee region.*

[12] *The estimates for the Upper Mississippi water resource region are exclusive of outflows from the Missouri region.*

[13] *The estimates for the Lower Mississippi water resource region represent conditions in all the upstream regions (Ohio, Tennessee, Upper Mississippi, Missouri, and Arkansas-White-Red regions).*

[14] *The estimates for the Lower Colorado water resources region represent conditions in both the Upper and Lower Colorado regions.*

[15] *The total for the contiguous U.S. includes data for the lower 48 States. Information on instream flow requirements was not available for the Hawaii, Alaska, or Caribbean regions.*

Source: After Flickinger (1987, table 28b) and Foxworthy and Moody (1986, table 7).

Although water is relatively scarce in the West as compared to the East, sufficient quantities do exist to meet demands to 2040 if water prices and institutions are allowed to change and bring demands into equilibrium with available supplies. Unfortunately, water institutions and pricing rarely work as effectively as economic theory might suggest. Consequently, shortages result from the failure of institutions to respond adequately to seasonal or long-term changes in the relative scarcity of water. It is probably too much to expect that our water institutions can eliminate scarcities resulting from climatological, physiographical, or edaphic changes in water availability. But institutions can deal more effectively with shortages rooted in prevailing institutional, technological, and economic frameworks.[1]

PLENTIFUL SUPPLIES

Water surpluses exist in all regions east of the Great Plains and the Pacific Northwest through 2040. In most cases, the surplus in an average rainfall year exceeds 10% of instream flow requirements for optimal habitat. In more than half the regions, the surplus exceeds 25% of instream flow requirements. In dry years, surpluses still exist in the Pacific Northwest and in all regions east of the Great Plains except the Lower Mississippi region. Surpluses in dry years still exceed instream flow requirements for good survival habitat by at least 10% through 2040.

The existence of surpluses through 2040 in these regions suggests that there is plenty of water available, on a regional basis, even in abnormally dry years. Surpluses provide a comfortable cushion of flow volume that guarantees continued abundance of both warm and cold water fisheries, assuming of course, that water quality is not limiting.

Surpluses represent regional conditions resulting from expected average annual precipitation if withdrawals or consumptive offstream uses are spread evenly across regions having surpluses. Consequently, even though a surplus is projected for a particular region (table 16), there will still be reaches of rivers and seasons when flows diminish to the point where good survival habitat is threatened.

USDA Forest Service (1981) contains a more detailed analysis of flow depletions than presented in this report. Results of that analysis show that even in many areas which have regional surpluses, there will be certain river drainages or reaches where low flows fall to less than 10% of the mean annual flow for several months each year. Extended periods of flows that low, coupled with quantities of oxygen-demanding wastes formerly discharged into streams in the 1950s and 1960s, resulted in the near-absence of sport fish in many drainages. Even non-sport fish were not prevalent. With a reduction in quantity of oxygen-demanding wastes discharged to these streams as a result of the Clean Water Act, fish populations expanded in many streams to the point where viable sport fish populations have emerged. The point is, however, that even though a surplus exists on an annual basis, water and related resource managers still have significant problems to contend with, albeit on a localized and intermittent basis.

Because ample flows exist in most water resource regions, there is no inconsistency between demand and supply projections. If both projections were plotted on the same axis, they would not intersect. Consequently, the lesser of the two curves, the demand projections, can be viewed as equilibrium projections. The excess supplies are not needed to satisfy current or projected needs. If water were produced and priced like a manufactured product, production output would be reduced to levels demanded over time. But because of the nature of the streamflow "production" process, cutbacks are not possible.

SHORTAGES

Lower Colorado Region

In years of average rainfall, the Lower Colorado water resource region faces significant water deficits. Deficits in an average year are more than instream flow requirement for optimal fish and wildlife habitat. In dry years, deficits are roughly 300% of the instream flow requirement for good survival habitat. Deficits are more than 400% of the regional groundwater overdraft level. Of all U.S. regions, the Lower Colorado has the most severe problems. Projections of recent trends suggest it will continue to have the most significant problems.

Analyses of the water budget for the Lower Colorado region were accomplished in two ways (table 17). The traditional approach is to include effects of supplies and demands from upstream tributary regions, which in this case is the Upper Colorado. A separate analysis excluding tributary regions also exists. The latter analysis illustrates the degree to which upstream regions are responsible for helping create deficits.

In 1985, irrigation consumed 87% of the 6.65 bgd average consumption in the Lower Colorado region (table 17). The deficit in an average year exceeds daily consumption by 865 million gallons per day. By 2040, irrigation consumption will drop to 82% of the 9.76 bgd consumed. Conservation measures likely to be adopted will lessen growth in the deficit over the projection period. Consumption is projected to increase 47% over the projection period while the deficit increased only 36% in the mean year (17% in the dry year).

Supply augmentation measures of the scale needed to eliminate the deficit are not likely to be implemented. Measures available are vegetation management, construction of snow-trapping structures, and weather modification. All are feasible for increasing or changing the season of runoff over a local area. But none has been implemented over a wide enough geographic area to evaluate its ability to make a significant contribution to reducing the projected deficit. The feasibility studies have shown that implementing such measures at the scale needed to eliminate the deficit will create regional environmental impacts on visual amenities and high-

Table 17.—Water consumption (million gallons per day) in the Lower Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use (including Upper Colorado)	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	6,900	6,300	8,700	7,200	6,300	5,830	6,912	7,227	7,529	7,766	7,986
Municipal central supplies	120	164	209	266	431	469	676	746	806	849	874
Industrial self-supplies	37	59	121	217	213	137	222	251	280	310	339
Thermoelectric steam cooling	15	33	58	107	179	156	278	333	376	433	501
Domestic self-supplies	8	7	20	30	44	36	31	32	32	33	33
Livestock watering	19	26	45	61	33	27	27	28	29	30	31
Total	7,099	6,589	9,153	7,881	7,200	6,655	8,147	8,617	9,053	9,420	9,764
Deficit - Mean Year[1]						7,520	8,910	9,580	9,680	9,980	10,240
Deficit - Dry Year[2]							8,510	9,210	9,350	9,660	9,950
Use (excluding Upper Colorado)	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**2000**	**2010**	**2020**	**2030**	**2040**
Irrigation	3,395	3,100	4,700	5,700	4,300	3,610	4,280	4,475	4,662	4,808	4,945
Municipal central supplies	110	150	190	240	390	434	626	691	747	786	809
Industrial self-supplies	32	51	100	190	150	115	186	211	235	260	285
Thermoelectric steam cooling	7	15	36	47	49	49	87	105	118	136	157
Domestic self-supplies	6	5	17	27	27	27	23	24	24	25	25
Livestock watering	12	16	28	47	11	14	14	14	15	16	16
Total	3,561	3,337	5,071	6,251	4,927	4,250	5,218	5,520	5,801	6,031	6,237
Deficit - Mean Year[1]						5,110	5,980	6,210	6,430	6,590	6,720
Deficit - Dry Year[2]							5,320	5,570	5,800	5,990	6,130

[1] *The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2] *The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

altitude vegetation far in excess of the impact level heretofore deemed acceptable. Thus, measures to increase supplies are unlikely to make a significant contribution to reducing the deficit. While supply management practices, such as storing runoff in a wet year for use in drier years, do make a significant contribution to satisfying demands, additional reservoir construction on the scale necessary to eliminate the deficit is not likely. Using imports to alleviate the deficit is unlikely given the interbasin agreements in place that regulate flows on the Lower Colorado River.

Groundwater overdrafts are 260% of non-irrigation consumption needs. Overdrafts are a short-term expedient for meeting current demands but eventually will exacerbate the problem. Using additional overdrafts to cure the deficit is not feasible. Consequently, two inescapable conclusions remain. Either we will continue to sacrifice wildlife and fish habitat and recreation potential dependent on instream flows that are at least 30% of the mean annual flow level (good survival habitat) or we must do a better job of curtailing consumption of water by offstream uses.

Instream flows in 1987 are less than 25% of those needed for optimal habitat. Projections of increased demand drive streamflow to less than 10% of optimal by 2000 in an average precipitation year and to negative streamflows in dry years. The latter is possible only by drawing down reservoir storage. By 2040, if recent use trends continue, negative flows will also occur in the mean year.

The magnitude of the deficit and magnitude of conservation measures implied by recent trends in consumption suggest that major new conservation measures will be necessary to cope with an unrelenting increase in deficits. Clearly, strong measures must be taken to deal with the deficit if long-term adverse impacts are to be avoided. Just as clearly, recent trends in increasing demands for water will have to be curtailed to reduce the deficit.

Because irrigation is the largest water consumer in the Lower Colorado region and because this water has the lowest price, it will likely be the use that bears the brunt of demand reduction. Reductions have already begun. Irrigation consumption peaked in 1975 at 5.7 bgd in the region. Since then, consumption has declined by 37% to 3.6 bgd. Further reductions will be necessary to bring supplies and demand into equilibrium. Compared to the 1980 use level, municipal demands have increased 11% to 434 mgd in 1985.

Prices for water are likely to rise as available supplies are rationed by market forces to their highest and best uses. Active markets for water rights have emerged in the states comprising the Lower Colorado region, and especially in Colorado. Institutional adjustments to provide additional freedom in buying and selling water rights are likely to occur to facilitate demand adjustments. Prices will climb as impediments to market functioning are eliminated. Many irrigators will find it quite profitable to liquidate water assets by selling rights to municipal water users. Lease-back arrangements may

become a popular method to retire land from irrigated agricultural production.

In summary, water consumption in the Lower Colorado region needs to decline to bring it into long-term equilibrium with available supplies. No other single factor or combination of factors has the potential for significantly reducing the water supply deficit. Prices for water are likely to rise substantially in the Lower Colorado region as shortages continue. Price increases will help bring demand and supply into equilibrium. The ultimate schedule of prices for water cannot be reliably projected, but the long-term equilibrium quantity resulting from price adjustments will probably be close to current supply levels.

Upper Colorado Region

The Upper Colorado region 1985 deficit was 350 mgd (table 18). However, demand projections indicate that deficits will rise to 1.84 bgd by 2040. The situation in this region is interesting because dry year assumptions project surpluses through 2020. The reason is the difference in instream flows necessary for optimal versus good survival habitat for fish and wildlife. The difference between these two instream flow assumptions makes the difference between deficits and surpluses. Projected deficits are between 5 and 30% of average stream outflows.

In the Upper Colorado region, the question whether or not to reduce the deficit depends on the degree to which anglers, hunters, and recreationists are content with less than optimal instream flows. If they are content with minor departures from the optimum, little needs to be done between now and 2020. If, on the other hand, departures from the optimum cause significant reductions in benefits from instream flows, then some moderate demand reduction measures can be taken. For example, if irrigation water usage is held at the 1985 level through 2040, half the projected deficits in the mean year can be eliminated. Remaining deficits would only be 13% of the optimal instream flow. This is probably a tolerable reduction from the optimum because the average rainfall is expected to be exceeded (and wash away the deficit) 5 years in 10.

The equilibrium flow rates will likely lie close to the long-term supply projection. Vegetation management, snow-trapping structures, and weather modification may make a contribution to eliminating a deficit of this magnitude. They are already being practiced in some eastern headwater watersheds in this region.

Rio Grande Region

The Rio Grande region has a current deficit and projected increases in deficits to 2040. In contrast to the Lower Colorado region where the deficit exceeds current and projected future consumption levels, the Rio Grande region deficit is only between 10% (today) and 37% (in 2040) of consumption levels in the average precipitation year (table 19). Deficits in dry years are 39% of projected use in 2000 and 49% in 2040.

Groundwater overdrafts are not used and imports are low at 2% of renewable supply. Neither offer much hope for reducing the deficit. To the west is the Lower Colorado region where interbasin transfers are strictly controlled and increasing exports would encounter insurmountable institutional barriers. The Arkansas-White-Red basin is to the north and east; but the closest drainages to the Rio Grande are not reliable sources of water for exports either. Using additional groundwater to eliminate the deficit is not likely because available aquifers are incapable of withstanding significant increases in withdrawals or short-term overdrafts. Additional reservoir developments of the magnitude needed to eliminate the deficit are not feasible given current conditions.

As in the Lower Colorado region, the greatest potential for reducing the deficit lies in curtailing consumption. If irrigation demands can be held at current levels throughout the projection period, 60% of the deficit can

Table 18.—Water consumption (million gallons per day) in the Upper Colorado water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	3,505	3,200	4,000	1,500	2,000	2,220	2,632	2,752	2,867	2,957	3,041
Thermoelectric steam cooling	8	18	22	60	130	107	191	229	258	297	344
Industrial self-supplies	5	8	21	27	63	22	36	40	45	50	54
Municipal central supplies	10	14	19	26	41	35	50	55	60	63	65
Livestock watering	7	10	17	14	22	13	13	13	14	14	15
Domestic self-supplies	2	2	3	3	17	9	8	8	8	8	8
Total	3,538	3,252	4,082	1,630	2,273	2,405	2,929	3,097	3,251	3,389	3,527
Deficit - Mean Year[1]						350	970	1,220	1,430	1,640	1,840
Deficit - Dry Year[2]							(390)[3]	(140)	90	310	520

[1]*The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2]*The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3]*Numbers in parentheses are negative deficits, i.e. surpluses.*

Table 19.—Water consumption (million gallons per day) in the Rio Grande water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	3,402	3,900	3,000	3,200	2,100	1,970	2,336	2,442	2,544	2,624	2,699
Municipal central supplies	124	110	150	190	140	146	210	232	251	264	272
Industrial self-supplies	31	46	97	55	13	46	75	84	94	104	114
Thermoelectric steam cooling	4	11	17	20	11	13	23	28	31	36	42
Domestic self-supplies	6	7	13	17	18	19	16	16	17	17	17
Livestock watering	13	68	36	37	26	39	39	40	42	43	44
Total	3,581	4,142	3,313	3,519	2,308	2,232	2,698	2,842	2,979	3,088	3,187
Deficit - Mean Year[1]						220	680	830	970	1080	1170
Deficit - Dry Year[2]							1040	1200	1340	1460	1570

[1]*The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2]*The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

be eliminated. Irrigation demand peaked at 3.9 bgd in 1965 and has since declined 49% to the 1985 level of 1.97 bgd. If an additional 16% decline in irrigation use can be attained by 2000, the deficit will disappear in the mean year and in the dry year the deficit would be 360 mgd or 17% of total consumption. Future deficits would likewise be about 6% of use in the mean year and 25% in dry years.

In summary, minor increases in water conservation measures for irrigation, followed by holding the line against further increases in irrigation water usage, will eliminate deficits in the Rio Grande region by 2000 and make deficits manageable for the remainder of the projection period. Projections of recent trends for nonagricultural water usage can be accommodated within this scenario. Equilibrium water usage will progress from 2.23 bgd in 1985 to 2.14 bgd in 2040, which is essentially the constant supply projection.

Great Basin Region

The Great Basin is projected to have surpluses in the average year through 2010, a negligible deficit in 2020 (2% of average stream outflow), and deficits necessitating a response beginning in 2030 (table 20). Significant dry year deficits do not emerge until 2010. In 2040 in a dry year, the projected deficit equals the expected instream flow.

Holding irrigation water usage at 1985 levels would more than eliminate the projected deficits through 2040, even in dry years. In fact, projections indicate that irrigation water usage could be allowed to increase 27% (3.2 bgd) through 2040 and supplies would still be adequate to meet demands in dry years. In this region, managing growth at a lower rate than prevalent since 1960 will suffice to assure adequate water supplies in dry years. The equilibrium between supply and demand will

Table 20.—Water consumption (million gallons per day) in the Great Basin water resource region, 1960 to 1985, with projections of consumption and water balance deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	8,000	10,000	10,000	9,900	11,000	12,000	14,227	14,875	15,496	15,984	16,439
Municipal central supplies	150	210	260	230	290	219	316	349	377	397	408
Industrial self-supplies	91	83	150	310	350	114	185	209	233	258	282
Thermoelectric steam cooling	0	0	0	9	2	25	45	53	60	69	80
Livestock watering	55	55	47	47	49	150	149	154	161	166	170
Domestic self-supplies	23	75	200	180	200	227	191	196	200	202	204
Total	8,319	10,423	10,657	10,676	11,891	12,735	15,113	15,836	16,528	17,077	17,583
Deficit - Mean Year[1]						(1,110)[3]	(370)	(150)	50	220	360
Deficit - Dry Year[2]							410	640	870	1,040	1,200

[1]*The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2]*The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3]*Numbers in parentheses are negative deficits, i.e. surpluses.*

follow demand projections to 2020 when deficits emerge. At that point, the equilibrium projection shifts to the supply line to 2040.

California Region

California has abundant water supplies in average years (table 21). Surpluses in years of average rainfall will exceed total consumption to 2030 and represent 94% of annual consumption in 2040. However, during dry years, significant deficits emerge. The deficit in 2000 during a dry year amounts to 35% of average stream outflow and grows by 2040 to 88% of average stream outflow in dry years.

California is a leader in moving water from locations of plentiful supply to areas where shortages are expected. Aqueducts of heroic length and capacity move water from drainages in the Sierras to the San Joaquin valley and Los Angeles metropolitan areas. Imports from the Lower Colorado region to the Los Angeles metropolitan area also occur. Of the regions, California typifies an area where imbalances between local demands and local supplies have been solved using structural methods. However, additional structural methods are unlikely to completely solve the deficit in dry years. The benefit stream for solving dry-year deficits is too irregular to justify additional structural solutions to the deficit problem given surpluses normally expected at least half the time.

Tradeoffs in California during dry years are similar to those outlined earlier for the Upper Colorado region. The extent to which demands in dry years should be curtailed to preserve good survival habitat for fish and wildlife and other instream water uses is about the same. If agricultural water usage in California can be held to 1985 levels, this action alone will eliminate 42% of the deficit in dry years. Further, this action will reduce the deficit to 51% of the instream flow requirement in dry years. With some additional conservation practices in dry years to reduce water consumption another 20%, limited detrimental impacts to good survival habitat could be tolerated 2 years in 10. Vegetation management, snow-trapping structures, and weather modification may help mitigate detrimental impacts to instream habitats in this region.

The equilibrium projection in California will follow the demand line in the average year. Equilibrium in a dry year will dip somewhat as demands are curtailed in response to more limited supplies of water.

Lower Mississippi Region

Like the California region, the Lower Mississippi region usually has abundant water supplies. In exceptionally dry years (such as the summer of 1988), instream flows can drop low enough to seriously impede navigation.

The Lower Mississippi region has five tributary regions—Ohio, Tennessee, Upper Mississippi, Missouri and Arkansas-White-Red regions. The water balance listed for the Lower Mississippi region includes effects of all tributary regions also (tables 16 and 22). If all regions simultaneously experienced dry-year rainfall, deficits emerge at 2000. Deficits are not large—2% of average stream outflow in 2000 rising to 10% of outflow in 2040. However, deficits in what has historically been thought of as a water-rich region were unexpected.

The two analyses in table 22 illustrate that water users in tributary areas are largely responsible for dry-year deficits in the Lower Mississippi region. Deficits are not projected for any of those regions, but the combined effect in a wide-spread dry year will create an externality on water users in the Lower Mississippi region.

Alleviating problems in dry years will require interstate cooperation. Such institutional cooperation has been rare because problems necessitating cooperation have rarely occurred. The U.S. Army Corps of Engineers has provided structural solutions to interstate flooding and navigation problems in these regions. But navigation and flood control structures can have only limited effect upon alleviating flow deficiencies. With offices and

Table 21.—Water consumption (million gallons per day) in the California water resource region, 1960 to 1985, with projections of consumption and water deficits to 2040

Use	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	13,000	16,000	21,000	21,000	23,000	19,200	22,764	23,799	24,794	25,574	26,302
Municipal central supplies	370	1,300	1,400	1,500	1,700	1,342	1,937	2,136	2,308	2,431	2,501
Industrial self-supplies	80	110	170	180	190	198	321	363	405	448	490
Thermoelectric steam cooling	17	18	24	32	41	68	120	143	162	186	215
Domestic self-supplies	120	51	73	76	84	91	77	79	80	81	82
Livestock watering	66	45	50	54	47	157	155	161	168	173	176
Total	13,653	17,524	22,717	22,842	25,062	21,056	25,372	26,681	27,917	28,893	29,767
Deficit - Mean Year[1]						(37,830)[3]	(33,240)	(31,740)	(30,320)	(29,160)	(28,080)
Deficit - Dry Year[2]							6,690	8,300	9,810	11,060	12,210

[1]*The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2]*The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3]*Numbers in parentheses are negative deficits, i.e. surpluses.*

Table 22.—Water consumption (million gallons per day) in the Lower Mississippi water resource region, 1960 to 1985, with projections of consumption to 2040

Use (including tributary regions)	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Irrigation	11,066	18,809	20,337	26,179	28,527	23,621	28,005	29,279	30,503	31,463	32,358
Municipal central supplies	898	1,136	1,236	1,380	1,534	1,740	2,510	2,769	2,992	3,151	3,242
Industrial self-supplies	1,206	1,489	1,462	1,710	1,957	1,456	2,360	2,669	2,979	3,291	3,605
Thermoelectric steam cooling	97	157	443	888	1,990	1,955	3,488	4,179	4,716	5,422	6,282
Domestic self-supplies	478	600	621	488	786	740	624	639	652	662	667
Livestock watering	939	1,020	1,065	1,159	1,101	1,373	1,361	1,414	1,477	1,524	1,553
Total	14,684	23,211	25,164	31,804	35,895	30,885	38,349	40,949	43,320	45,513	47,707
Deficit - Mean Year[1]						(18,060)[3]	(10,780)	(7,930)	(5,260)	3,840	6,550
Deficit - Dry Year[2]							6,410	9,950	12,780	23,320	26,190
Use (excluding tributary regions)	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**2000**	**2010**	**2020**	**2030**	**2040**
Irrigation	660	1,200	2,200	4,000	4,800	4,400	5,217	5,454	5,682	5,861	6,028
Municipal central supplies	110	200	240	310	400	156	225	248	268	282	291
Industrial self-supplies	380	450	780	810	740	200	324	367	409	452	495
Thermoelectric steam cooling	19	20	190	290	400	325	580	695	784	901	1,044
Domestic self-supplies	52	58	100	68	67	92	77	79	81	82	83
Livestock watering	41	44	55	47	41	348	345	358	374	386	394
Total	1,262	1,972	3,565	5,525	6,448	5,521	6,768	7,201	7,599	7,965	8,334
Deficit - Mean Year[1]						(105,280)	(102,700)	(101,380)	(100,090)	(98,840)	(97,570)
Deficit - Dry Year[2]							(25,600)	(24,280)	(22,990)	(21,740)	(20,470)

[1]*The deficit in the mean year assumes the precipitation level that will be exceeded 5 years in 10 and the instream flows needed for optimal fish and wildlife habitat (See notes 2 and 9, table 16).*

[2]*The deficit in the dry year assumes the precipitation level that will be exceeded 8 years in 10 and the instream flows needed for good survival habitat for fish and wildlife (see notes 2 and 9, table 16).*

[3]*The numbers in parentheses are negative deficits, that is, surpluses.*

contacts in all the states and with membership and leadership roles in most major river basin commissions, the Corps is well positioned institutionally to help address the water deficit externality when it occurs.

SUMMARY

Four common themes emerged from the analyses of surpluses and deficits in the Rio Grande, Upper and Lower Colorado, Great Basin, California, and Lower Mississippi water resource regions.

The first is that the impetus to resolve deficits will come from a desire to mitigate adverse impacts on fish and wildlife habitat, recreation use, and navigation caused by low instream flows. Fishing and water-based recreation are both extremely popular activities. Many bulk agricultural and industrial commodities are transported by barges throughout the mid-west, so maintaining navigation is vital to commerce from the Appalachians to the Rockies. Adequate instream flows are essential for all these uses. If benefits from activities decline, users will demand that responsible public officials take action or litigation will likely follow. Public sentiment is strong to preserve habitat and recreational opportunities and commercial interests strongly endorse maintaining navigation.

The second theme is that irrigation is the predominant consumptive use and accounts for more than three-fourths of all use in each region. Irrigation is also the lowest-value offstream use in all regions. Thus, eliminating deficits will require some reduction in the projected rates of growth in irrigation water usage. Experts recently concluded that irrigated crop production is on the verge of a major shift away from historical trends in acres irrigated and water usage (Department of Agriculture 1987). The Appraisal contains three scenarios projecting cropland and pasture production to 2030. If the intermediate scenario occurs, acreage of irrigated cropland will drop 19 million acres between 1982 and 2030 to 44 million acres. Irrigation water usage will drop commensurately. A significant portion of the decline will occur in the five regions where shortages are projected. Changes in irrigation practices outlined by the Department of Agriculture (1987, Chapter 7) will lead to additional reductions in total irrigation water usage. It appears that reductions in irrigation water usage will make a significant contribution to eliminating water supply deficits over the next 40 to 50 years.

The third theme is that non-structural approaches such as modifications in water rights institutions, freer functioning of water markets, and improved interstate cooperation will play the dominant role in solving water supply deficits. The days of using structural approaches as the dominant way to reducing deficits are past. For example, proposals for new reservoirs are encountering increasing amounts of public opposition in spite of support by local agricultural interests. High-quality dam sites

have long since been used. Potential sites remaining have difficulties of one form or another, including geological, environmental, economic, or institutional. Chapter 7 of the Appraisal contains an overview of non-structural changes and their potential for helping alleviate shortages.

The fourth theme is that water yield augmentation by vegetation management, building snow-trapping structures, and weather modification can help remedy small deficits. However, these techniques are unlikely to be employed as the dominant way of eliminating major deficits.

ALTERNATIVE FUTURES

The supply/demand situations outlined in tables 16 to 22 are based on assumptions that changes in consumption from 1960 to 1985 are the best basis for projecting changes in consumption from 1990 to 2040.

Alternative future scenarios of supply and demand were developed for this report and result in changes in surpluses and deficits reported in tables 16 to 22. The approach to specifying alternative futures for water was to consider two alternative rates of change in demand. These are 13% higher demands in 2000 and 20% higher from 2010 to 2040; and 13% lower demands in 2000 and 20% lower from 2010 to 2040. For other resources, supply trend increases 20% above and below the long-term trend were also evaluated. In this report, supply changes were associated with assumptions about effects of potential changes in global climates. These assumptions led to supply reductions of between 5 and 40% depending upon the region. A supply increase is not shown.

DEMAND 20% HIGHER THAN PROJECTED

Alternative futures for demand lead to shifts in surpluses and deficits (table 23). All regions that had surpluses under the baseline Assessment demand assumption (except the Texas-Gulf) continue to have surpluses even if demand is increased 20%. In dry years in the Texas-Gulf region, deficits begin in 2020 and continue to 2040.

Deficits appear earlier in the Great Basin. Under the Assessment baseline projection, deficits appeared in 2000 for the dry year and 2020 for the average rainfall year. If demand is 20% higher than projected, the first deficit appears only a decade from now in 2000 under both rainfall conditions. In addition, deficits are much larger—190% (2040 dry) to 250% (2010 dry).

In California, deficits still do not appear in years of average rainfall even if demand is 20% greater than expected. In dry years, deficits are about 50% larger.

In the Lower Mississippi region, deficits appear a decade earlier in years of average rainfall—2020 versus 2030. In addition, deficits are 145% larger—16.1 bgd versus 6.6 bgd by 2040. In dry years, deficits appear by 2000 if demand is 20% higher. Dry-year deficits are also larger for the higher demand—40% (2040) to 87% (2000).

DEMAND 20% LOWER THAN PROJECTED

Lower demand seems much more likely than increased demand, according to the projected decline in irrigated acreage of 19 million acres in Department of Agriculture (1987). Demand reductions generally postpone the beginning of deficits and reduce their intensity.

In the Rio Grande region where a 220 mgd deficit occurs now in average years, a 20% drop in demand would halve deficits in average rainfall years. In dry years, the reduction in demand reduces deficits to roughly 60% of the level originally projected.

In the Upper Colorado region, reducing demand 20% eliminates deficits in dry years and provides good survival habitat. However, a 20% reduction in demand still is not enough to eliminate deficits and provide optimal habitat in the average-rainfall year. Deficits in the average year are only 60% of those under baseline demands. The demand reduction is still not enough to provide optimal fish and wildlife habitat and optimal instream flows for recreation. On the other hand, deficits that remain are between 15 and 20% of optimal levels for habitat and recreation; low enough that many users may not notice the difference.

The demand drop does not significantly reduce projected deficits in the Lower Colorado region. Deficits still hover around 80% of baseline deficits.

In the Great Basin region, a 20% drop in projected demand would eliminate all deficits in average rainfall years. In the dry years, deficits will amount to 100 mgd or about 8% of instream flows in 2040.

In California, a 20% drop in demand by 2040 would result in the largest absolute regional reduction in consumption, 5.4 bgd. A drop of this magnitude would reduce deficits in dry years to between 3 and 6 bgd, or 15% to 30% of average streamflow. These percentages are still large enough to create problems in a dry year but small enough to be manageable with reservoir storage saved from wetter years.

SUPPLY REDUCTIONS DUE TO GLOBAL CLIMATE CHANGES

A number of researchers and agencies have projected increases in the average annual global air temperature over the next 50 to 150 years. Projected rising temperatures are a function of projected increases in concentrations of atmospheric carbon dioxide and other infrared-active gasses stemming from growth in the combustion of fossil fuels. Projections of temperature increases are based on recently developed atmospheric general circulation models (GCMs). Outputs from state-of-the-art GCMs agree on the degree of hemispheric and global warming. However, Gleick (1986) noted that researchers of climate changes are faced with the dilemma that GCMs capable of providing information on the likely effects of human activities on global climate are unsuited for evaluating the nature and magnitude of important regional effects, especially those involving regional hydrology.

Table 23.—Surpluses and deficits (billion gallons per day) resulting from alternative demand futures, by water resource regions

		Surpluses or deficits[1]					
		Normal Expected Supplies; Projected Demands			Supplies Expected if Global Climate Changes; Projected Demands (see note)		
Water resource region	Rainfall Condition	-20 percent	Normal	+20 percent	-20 Percent	Normal	+20 Percent
New England	1985 avg.	7.83	7.76	7.70	3.63	3.48	3.33
	2000 avg.	7.72	7.63	7.54	3.35	3.13	2.90
	2000 dry	15.17	15.08	14.99	11.54	11.32	11.10
	2010 avg.	7.69	7.58	7.48	3.24	2.99	2.74
	2010 dry	15.14	15.03	14.93	11.44	11.19	10.94
	2020 avg.	7.65	7.54	7.43	3.15	2.88	2.61
	2020 dry	15.10	14.99	14.88	11.35	11.07	10.80
	2030 avg.	7.62	7.50	7.38	3.06	2.77	2.48
	2030 dry	15.07	14.95	14.83	12.13	11.83	11.54
	2040 avg.	7.59	7.47	7.34	2.98	2.66	2.35
	2040 dry	15.04	14.92	14.79	11.18	10.86	10.54
Mid-Atlantic	1985 avg.	25.37	25.03	24.68	20.51	20.15	19.79
	2000 avg.	24.77	24.27	23.77	19.86	19.34	18.82
	2000 dry	14.23	13.74	13.24	10.34	9.81	9.28
	2010 avg.	24.53	23.97	23.41	19.60	19.01	18.43
	2010 dry	14.00	13.44	12.88	10.08	9.48	8.88
	2020 avg.	24.32	23.71	23.10	19.37	18.73	18.09
	2020 dry	13.79	13.18	12.57	9.85	9.19	8.54
	2030 avg.	24.12	23.46	22.80	19.14	18.45	17.75
	2030 dry	13.59	12.93	12.27	9.62	8.91	8.19
	2040 avg.	23.92	23.21	22.50	18.90	18.15	17.39
	2040 dry	13.39	12.68	11.96	9 .38	8.61	7.83
South Atlantic-Gulf	1985 avg.	19.84	18.84	17.85	-1.70	-2.75	-3.80
	2000 avg.	18.73	17.46	16.20	-2.91	-4.27	-5.62
	2000 dry	21.13	19.86	18.60	4.79	3.30	1.81
	2010 avg.	18.27	16.89	15.51	-3.36	-4.82	-6.28
	2010 dry	20.67	19.29	17.91	4.32	2.71	1.11
	2020 avg.	17.86	16.37	14.88	-3.76	-5.33	-6.90
	2020 dry	20.26	18.77	17.28	3.89	2.17	0.46
	2030 avg.	17.46	15.87	14.29	-4.15	-5.81	-7.47
	2030 dry	19.86	18.27	16.69	3.49	1.67	-0.14
	2040 avg.	17.07	15.39	13.71	-4.52	-6.28	-8.03
	2040 dry	19.47	17.79	16.11	3.10	1.18	-0.73
Great Lakes	1985 avg.	10.24	9.99	9.73	5.63	5.19	4.74
	2000 avg.	9.91	9.57	9.24	4.61	3.91	3.21
	2000 dry	12.07	11.74	11.40	7.49	6.78	6.06
	2010 avg.	9.77	9.39	9.02	4.18	3.37	2.56
	2010 dry	11.93	11.56	11.19	7.06	6.24	5.41
	2020 avg.	9.64	9.23	8.83	3.82	2.92	2.02
	2020 dry	11.80	11.40	11.00	6.70	5.79	4.87
	2030 avg.	9.51	9.08	8.64	3.41	2.41	1.41
	2030 dry	11.68	11.24	10.81	6.29	5.27	4.25
	2040 avg.	9.39	8.93	8.46	2.93	1.81	0.69
	2040 dry	11.56	11.09	10.63	5.80	4.67	3.53
Ohio	1985 avg.	16.07	15.69	15.31	8.82	8.38	7.93
	2000 avg.	15.48	14.95	14.41	7.84	7.15	6.46
	2000 dry	21.15	20.62	20.09	15.10	14.40	13.70
	2010 avg.	15.17	14.57	13.96	7.42	6.62	5.83
	2010 dry	20.85	20.24	19.64	14.68	13.87	13.07
	2020 avg.	14.92	14.25	13.58	7.07	6.18	5.30
	2020 dry	20.60	19.93	19.26	14.32	13.43	12.54
	2030 avg.	14.63	13.89	13.15	6.65	5.67	4.68
	2030 dry	20.31	19.56	18.82	13.91	12.91	11.92
	2040 avg.	14.31	13.49	12.66	6.19	5.08	3.98
	2040 dry	19.98	19.16	18.34	13.44	12.33	11.21
Tennessee	1985 avg.	4.51	4.43	4.35	0.20	0.12	0.05
	2000 avg.	4.43	4.33	4.23	0.06	-0.05	-0.15
	2000 dry	11.77	11.67	11.57	8.45	8.35	8.24
	2010 avg.	4.38	4.27	4.16	0.01	-0.11	-0.23
	2010 dry	11.72	11.61	11.50	7.86	7.74	7.62
	2020 avg.	4.33	4.21	4.09	-0.04	-0.17	-0.30
	2020 dry	11.68	11.56	11.43	7.81	7.68	7.55
	2030 avg.	4.29	4.16	4.03	-0.08	-0.22	-0.36
	2030 dry	11.63	11.50	11.37	7.77	7.63	7.48
	2040 avg.	4.25	4.10	3.96	-0.13	-0.28	-0.44
	2040 dry	11.59	11.45	11.30	7.72	7.57	7.41
Upper Mississippi	1985 avg.	10.37	10.06	9.75	6.14	5.77	5.40
	2000 avg.	9.98	9.58	9.17	5.61	5.11	4.61
	2000 dry	16.65	16.25	15.84	12.92	12.39	11.87
	2010 avg.	9.80	9.34	8.89	5.39	4.84	4.29

Table 23.—Surpluses and deficits (billion gallons per day) resulting from alternative demand futures, by water resource regions—Continued

	2010 dry	16.46	16.01	15.56	12.70	12.12	11.54
	2020 avg.	9.64	9.15	8.66	5.21	4.61	4.01
	2020 dry	16.31	15.82	15.33	12.51	11.88	11.25
	2030 avg.	9.47	8.94	8.40	5.02	4.38	3.73
	2030 dry	16.14	15.60	15.07	12.32	11.64	10.97
	2040 avg.	9.28	8.70	8.12	4.84	4.15	3.46
	2040 dry	15.95	15.37	14.79	12.13	11.41	10.69
Lower Mississippi	1985 avg.	83.99	77.29	70.59	-24.87	-31.05	-37.22
	2000 avg.	76.19	67.87	59.55	-30.65	-38.32	-45.99
	2000 dry	-3.92	-12.99	-22.06	-29.92	-38.48	-47.04
	2010 avg.	72.92	64.01	55.10	-32.99	-41.18	-49.37
	2010 dry	-7.32	-17.02	-26.72	-32.90	-42.02	-51.15
	2020 avg.	69.90	60.45	51.00	-35.18	-43.85	-52.51
	2020 dry	-10.47	-20.74	-31.01	-35.21	-44.85	-54.49
	2030 avg.	66.98	57.03	47.08	-43.84	-52.94	-62.05
	2030 dry	-13.49	-24.29	-35.09	-45.29	-55.39	-65.50
	2040 avg.	64.00	53.53	43.06	-46.11	-55.65	-65.19
	2040 dry	-16.58	-27.92	-39.26	-47.69	-58.26	-68.83
Souris-Red-Rainy	1985 avg.	3.54	3.52	3.49	3.14	3.11	3.08
	2000 avg.	3.52	3.49	3.46	3.11	3.08	3.04
	2000 dry	1.56	1.53	1.50	1.30	1.27	1.23
	2010 avg.	3.51	3.48	3.45	3.10	3.06	3.03
	2010 dry	1.55	1.52	1.49	1.29	1.25	1.21
	2020 avg.	3.50	3.47	3.44	3.09	3.05	3.01
	2020 dry	1.54	1.51	1.48	1.28	1.24	1.19
	2030 avg.	3.50	3.47	3.43	3.09	3.05	3.01
	2030 dry	1.54	1.51	1.47	1.28	1.23	1.19
	2040 avg.	3.49	3.46	3.43	3.08	3.03	2.99
	2040 dry	1.53	1.50	1.47	1.27	1.22	1.17
Missouri	1985 avg.	20.67	17.72	14.78	8.70	6.14	3.57
	2000 avg.	17.37	13.80	10.23	5.88	2.81	-0.27
	2000 dry	14.91	11.34	7.78	5.54	2.18	-1.18
	2010 avg.	16.05	12.28	8.52	4.70	1.47	-1.77
	2010 dry	13.55	9.79	6.02	4.27	0.74	-2.79
	2020 avg.	14.79	10.85	6.90	3.57	0.19	-3.20
	2020 dry	12.25	8.31	4.36	3.05	-0.64	-4.33
	2030 avg.	13.64	9.54	5.44	2.55	-0.96	-4.46
	2030 dry	10.98	6.89	2.79	1.87	-1.95	-5.78
	2040 avg.	12.51	8.26	4.01	1.56	-2.06	-5.68
	2040 dry	9.80	5.55	1.30	0.80	-3.15	-7.10
Arkansas-White-Red	1985 avg.	12.76	10.99	9.22	0.62	-1.00	-2.62
	2000 avg.	10.62	8.45	6.27	-1.19	-3.13	-5.07
	2000 dry	13.97	11.79	9.61	5.50	3.20	0.91
	2010 avg.	9.73	7.41	5.09	-1.93	-3.98	-6.02
	2010 dry	13.07	10.75	8.43	4.69	2.28	-0.14
	2020 avg.	8.87	6.42	3.98	-2.66	-4.81	-6.96
	2020 dry	12.22	9.77	7.32	3.89	1.37	-1.16
	2030 avg.	8.07	5.50	2.94	-3.31	-5.54	-7.77
	2030 dry	11.41	8.85	6.28	3.20	0.58	-2.04
	2040 avg.	7.24	4.55	1.87	-3.97	-6 27	-8.57
	2040 dry	10.58	7.90	5.21	2.50	-0.21	-2.91
Texas-Gulf	1985 avg.	9.45	8.24	7.03	-1.37	-2.60	-3.82
	2000 avg.	8.11	6.59	5.06	-2.70	-4.23	-5.76
	2000 dry	4.14	2.61	1.09	-2.26	-3.91	-5.55
	2010 avg.	7.63	5.99	4.36	-3.15	-4.79	-6.43
	2010 dry	3.65	2.01	0.38	-2.74	-4.49	-6.24
	2020 avg.	7.17	5.44	3.70	-3.59	-5.33	-7.06
	2020 dry	3.20	1.46	-0.28	-3.20	-5.05	-6.91
	2030 avg.	6.76	4.92	3.09	-3.96	-5.78	-7.60
	2030 dry	2.78	0.95	-0.88	-3.59	-5.53	-7.46
	2040 avg.	6.34	4.41	2.48	-4.31	-6.20	-8.10
	2040 dry	2.36	0.43	-1.49	-3.94	-5.96	-7.98
Rio Grande	1985 avg.	0.37	-0.04	-0.45	-1.27	-1.72	-2.16
	2000 avg.	0.01	-0.49	-1.00	-1.65	-2.18	-2.72
	2000 dry	-0.11	-0.61	-1.11	-1.68	-2.27	-2.85
	2010 avg.	-0.10	-0.63	-1.15	-1.76	-2.33	-2.90
	2010 dry	-0.22	-0.74	-1.27	-1.81	-2.43	-3.04
	2020 avg.	-0.20	-0.75	-1.30	-1.87	-2.47	-3.06
	2020 dry	-0.32	-0.87	-1.42	-1.92	-2.57	-3.22
	2030 avg.	-0.27	-0.85	-1.42	-1.96	-2.58	-3.19
	2030 dry	-0.39	-0.96	-1.54	-2.02	-2.69	-3.36
	2040 avg.	-0.34	-0.93	-1.52	-2.04	-2.67	-3.31
	2040 dry	-0.46	-1.05	-1.64	-2.10	-2.79	-3.48
Upper Colorado	1985 avg.	0.37	-0.05	-0.46	-4.79	-5.27	-5.75
	2000 avg.	-0.13	-0.64	-1.16	-5.31	-5.89	-6.48
	2000 dry	1.51	0.99	0.47	-2.84	-3.48	-4.11
	2010 avg.	-0.34	-0.89	-1.45	-5.52	-6.14	-6.75
	2010 dry	1.30	0.74	0.19	-3.05	-3.73	-4.40

Table 23.—Surpluses and deficits (billion gallons per day) resulting from alternative demand futures, by water resource regions—Continued

	2020 avg.	-0.52	-1.11	-1.69	-5.70	-6.35	-7.00
	2020 dry	1.11	0.52	-0.06	-3.25	-3.96	-4.66
	2030 avg.	-0.71	-1.33	-1.95	-5.88	-6.56	-7.24
	2030 dry	0.92	0.30	-0.31	-3.44	-4.18	-4.91
	2040 avg.	-0.91	-1.56	-2.20	-6.06	-6.76	-7.47
	2040 dry	0.72	0.08	-0.57	-3.62	-4.39	-5.15
Lower Colorado	1985 avg.	-6.06	-7.36	-8.66	-11.54	-12.88	-14.21
	2000 avg.	-7.19	-8.80	-10.41	-12.64	-14.27	-15.90
	2000 dry	-6.63	-8.37	-10.11	-10.96	-12.73	-14.50
	2010 avg.	-7.51	-9.22	-10.93	-13.16	-14.94	-16.71
	2010 dry	-6.98	-8.83	-10.67	-11.50	-13.43	-15.35
	2020 avg.	-7.82	-9.62	-11.42	-13.23	-15.04	-16.85
	2020 dry	-7.31	-9.26	-11.20	-11.61	-13.57	-15.53
	2030 avg.	-8.06	-9.94	-11.82	-13.46	-15.34	-17.22
	2030 dry	-7.57	-9.60	-11.62	-11.84	-13.88	-15.92
	2040 avg.	-8.28	-10.23	-12.18	-13.65	-15.60	-17.56
	2040 dry	-7.81	-9.92	-12.02	-12.06	-14.17	-16.29
Great Basin	1985 avg.	1.91	1.21	0.51	-0.25	-0.98	-1.70
	2000 avg.	1.26	0.40	-0.46	-0.84	-1.70	-2.57
	2000 dry	0.88	0.02	-0.84	-1.21	-2.16	-3.11
	2010 avg.	1.07	0.16	-0.75	-1.01	-1.92	-2.83
	2010 dry	0.70	-0.21	-1.12	-1.40	-2.40	-3.39
	2020 avg.	0.89	-0.06	-1.01	-1.18	-2.13	-3.08
	2020 dry	0.52	-0.44	-1.39	-1.58	-2.62	-3.66
	2030 avg.	0.75	-0.24	-1.23	-1.31	-2.29	-3.28
	2030 dry	0.38	-0.61	-1.60	-1.73	-2.80	-3.88
	2040 avg.	0.63	-0.39	-1.41	-1.42	-2.44	-3.45
	2040 dry	0.25	-0.77	-1.79	-1.85	-2.96	-4.07
Pacific Northwest	1985 avg.	67.94	65.82	63.71	37.11	34.57	32.02
	2000 avg.	66.22	63.68	61.13	35.21	32.19	29.16
	2000 dry	60.14	57.59	55.05	31.37	27.78	24.18
	2010 avg.	65.71	63.04	60.36	34.63	31.46	28.30
	2010 dry	59.63	56.95	54.28	30.69	26.92	23.15
	2020 avg.	65.22	62.42	59.63	34.08	30.77	27.47
	2020 dry	59.14	56.34	53.55	30.04	26.11	22.17
	2030 avg.	64.83	61.93	59.04	33.64	30.22	26.81
	2030 dry	58.74	55.85	52.96	29.52	25.46	21.40
	2040 avg.	62.58	59.13	55.68	33.23	29.72	26.20
	2040 dry	56.50	53.05	49.59	29.04	24.86	20.68
California	1985 avg.	41.17	36.74	32.31	24.67	20.45	16.24
	2000 avg.	36.98	31.55	26.12	20.93	15.86	10.78
	2000 dry	-0.65	-6.09	-11.52	-9.71	-15.24	-20.77
	2010 avg.	35.73	30.02	24.31	19.70	14.36	9.02
	2010 dry	-1.91	-7.62	-13.33	-11.03	-16.84	-22.66
	2020 avg.	34.55	28.57	22.59	18.53	12.94	7.36
	2020 dry	-3.09	-9.07	-15.05	-12.27	-18.36	-24.44
	2030 avg.	33.60	27.41	21.22	17.56	11.78	6.00
	2030 dry	-4.04	-10.23	-16.42	-13.31	-19.60	-25.90
	2040 avg.	32.74	26.37	19.99	16.66	10.70	4.75
	2040 dry	-4.90	-11.27	-17.65	-14.27	-20.75	-27.23
Total contiguous U.S.	1985 avg.	257.09	238.41	219.73	107.59	88.90	70.22
	2000 avg.	237.58	214.42	191.25	88.08	64.91	41.75
	2000 dry	107.27	81.63	56.00	3.39	-22.25	-47.89
	2010 avg.	230.27	205.53	180.80	80.76	56.03	31.30
	2010 dry	99.51	72.20	44.88	-4.37	-31.69	-59.00
	2020 avg.	223.88	197.82	171.75	74.37	48.31	22.25
	2020 dry	92.69	63.93	35.17	-11.20	-39.96	-68.71
	2030 avg.	230.06	202.76	175.47	80.55	53.26	25.96
	2030 dry	86.38	56.31	26.24	-17.51	-47.58	-77.65
	2040 avg.	212.02	183.52	155.03	62.52	34.02	5.52
	2040 dry	80.18	48.83	17.47	-23.70	-55.06	-86.42

[1]*The surplus or deficit for normal expected supplies and normal projected demand comes from Table 16. The projected demand is presented in Table 16 as the offstream consumptive use for agricultural and non-agricultural uses. To compute the surpluses and deficits in this table, the offstream consumptive uses in Table 16 were decreased and increased by 13% in 2000, growing to 20% by 2040. The surplus or deficit expected if global climate changes uses the same demands as the first three columns but reduces the renewable water supply, table 16, from 5% to 40% depending upon the region.*

Information on regional effects is important for determining appropriate policy responses to climatic changes. Gleick concluded that until realistic surface hydrology responses can be incorporated into GCMs with regional resolution, evaluating regional and local hydrologic effects will only be accomplished by using other methods, such as regional water balance models. Gortch (1988) reviewed four state-of-the-art GCMs and reached the same conclusion; quantitative prediction of anything approaching even a multi-state region is not yet possible.

Observations about the onset of warming in North America have been mixed. Part of the reason is changing urban development patterns in the vicinity of long-term weather observation stations. As areas surrounding observation stations become more developed, pavement and buildings absorb and reradiate more heat than

previously. Consequently, recorded temperatures climb. It is not unusual for thermometers in urban settings to register 2° to 3° Celsius (C) or 3.6° to 5.4° Farenheit (F), higher than thermometers in nearby rural areas.

Hilts (1989) reported results of a National Oceanic and Atmospheric Administration (NOAA) study by Karl of temperature records for the contiguous U.S. from 1895 to the present. This study is the most comprehensive one to eliminate the growing effect of increasing urbanization on recorded air temperatures. In looking at U.S. temperatures, NOAA researchers did not find a trend toward warmer average temperatures. The annual average air temperature over the past century was 11.4° C (52.5° F). Annual averages varied between 10.5° and 12.8° C (51° and 55° F), but the difference between the average for the century and the annual average for any one year does not seem to be rising. Examination of average daily highs and lows revealed that highs have remained roughly the same, while lows rose about 0.3° C, especially in the last two decades. This reduction in the daily temperature range is consistent with the kind of response scientists expect from the "greenhouse effect," but it does not prove the effect is occurring. These findings appear to be at odds with the results of Hansen and Lebedeff (1987), who found that global warming has amounted to about 0.5° C. Hansen (1989) noted that the contiguous United States amounts to 2% of global area. Findings reported by Hilts (1989) come from too small a sample of the global surface to provide any definitive conclusions.

Data since 1860 from around the world show that the five warmest years in the history of instrumental measurements are all in the 1980s (1980, 1981, 1983, 1987, and 1988). Hansen (1989) believes this is an indication of the onset of a long-term warming trend. Karl, quoted in Hilts (1989), counters that early instruments and data collection methods gave distorted readings compared to modern techniques. Unanimity on the data, much less the findings, does not exist.

Calculations by Hansen plus other studies in the literature which look ahead 50–150 years report a variety of projected temperature increases ranging from 1° to 9° C. Flaschka et al. (1987) concluded that the most commonly cited projection is an increase of 2° C (4.5° F).

Reports differ on how an increase in hemispheric average annual air temperature of 2° C is likely to affect precipitation, largely because precipitation effects are presumed to vary by latitude and elevation. Consequently, hydrologic analyses are usually made for two precipitation assumptions arising from a 2° C temperature increase. They are a 10% increase in precipitation from current levels and a 10% decline from current levels. Of these precipitation assumptions, the 10% decline is of more interest when analyzing projected surpluses and deficits from a supply-demand perspective. Stockton and Boggess (1979) analyzed climate scenarios involving a 2° C temperature increase and a plus and minus 10% change in mean precipitation for all water resource regions in the U.S. They concluded that a change toward a warmer and drier climate would have impacts nationwide. The most severe effects are west of the 100th Meridian (except for the water-rich Pacific Northwest and the Great Basin, where demand is low and groundwater reserves relatively high). The humid East would not be seriously affected.

Some detailed regional analyses have been performed. For example, Flaschka et al. (1987) created a water balance model for the Great Basin region. They concluded that the most probable change in annual runoff resulting from a 2° C increase and a 10% precipitation decline would be a reduction of 17% to 28%. A 25% decrease in precipitation would reduce runoff 33% to 51%. Revelle and Waggoner (1983) studied the Upper Colorado region and concluded that a 2° C increase and 10% precipitation reduction would reduce annual flows about 40%. This may be a sufficient reduction to require renegotiation of the 1944 treaty between the United States and Mexico on the allocation of flows from the Colorado River. Stockton and Boggess (1983) reported that a similar scenario would cause a 30% reduction in flow for selected sub-basins of the Rio Grand region.

Reductions in runoff of these magnitudes result from projections that temperatures will remain warm enough in autumn so that precipitation which now comes as snow in autumn and early winter will instead come mostly as rain. The aridity of a watershed is a principal factor in determining how runoff will change in response to such changes in the nature of precipitation. When the soil temperature is above 0° C, rainfall will infiltrate the soil and percolate to aquifers. Manabe, an expert on the precipitation factor of GCMs and cited in Rowan (1986), expects more wintertime precipitation in the middle latitudes as a result of global warming. But because temperatures are warmer, more precipitation would fall as rain, resulting in less snowpack and an earlier but smaller springtime runoff. However, at high elevations where temperatures below 0° C are still expected despite global warming, extra precipitation would probably fall as snow and springtime runoff from these drainages would be higher and earlier. Thus, there may be an increased risk of flood damages from runoff.

Effects of global climate change in this report are simulated by percentage reductions in renewable water supplies of between 5% and 40% depending upon the water resource region (table 23). Reductions of 5% were projected for the New England, Mid-Atlantic, Great Lakes, Ohio, Upper Mississippi, and Souris-Red-Rainey regions. Reductions of 10% were projected for South Atlantic-Gulf, Tennessee, Lower Mississippi, and Pacific Northwest regions. Reductions of 20% were projected for the Missouri, Arkansas-White-Red, and California regions. Great Basin supplies were reduced 25%, Texas-Gulf and Rio Grande supplies reduced by 30%, and Upper and Lower Colorado supplies reduced by 40%. These percentage reductions are consistent with reductions summarized in Smith and Tirpak (1988). All reductions were assumed to be in effect by 2000 (table 23).

If global warming induces the supply changes outlined, deficits emerge in several additional southern regions. In the South Atlantic-Gulf and Arkansas-White-Red regions, insufficient flows remain in average rainfall years to provide optimal instream habitat for fish and

wildlife under all assumed demand levels. However, adequate survival habitat will remain, even in dry years, until 2020 or 2030. Similar results emerge in the Tennessee region, but deficits are negligible. The Texas-Gulf region will experience much more serious deficits in both average and dry years. Fish and wildlife habitat and other instream uses will definitely be in conflict with offstream uses in this region, even if demands drop 20% by 2040. Other regions which experience deficits under the current climatic situation will experience more serious deficits if global warming occurs. Environmental effects of projected flow levels are described in more detail in Smith and Tirpak (1988).

The uncertainty attached to climate change forecasts has implications for water resource managers. For example, managers should emphasize preservation of flexibility and robustness when designing, modifying, or rehabilitating structures and operating procedures. Investments in irreversible, inflexible, large scale, or high-cost measures should be avoided. The potential reduction in supplies adds additional impetus to finding new ways to reduce demand. Smith and Tirpak (1988) note that new approaches to managing water resources are not needed as much as the resolve to implement recommendations made repeatedly in water assessments since 1960. Our challenge is to act on the recommendations now in the face of uncertainty.

SUMMARY

Demand reductions are the more likely scenario given a 19-million-acre reduction in irrigated acreage projected in Department of Agriculture (1987). On a national basis, the projected drop in irrigated acreage amounts to a 30% reduction. Because consumptive use for irrigation amounts to 75% of total consumptive use, a 30% drop in acreage equates roughly to a 25% drop in total water consumption. For the 30% drop in irrigated acreage to occur, the assumptions of the Appraisal will need to be fulfilled. Chief among these are gains in crop yields from genetic improvement, gains from adoption of new technologies, and drastic changes in crop price support programs. The interested reader should see the Appraisal for a detailed discussion of assumptions underlying the decline in irrigated acreage.

A reduction in demand of 20% will alleviate deficits in the Lower and Upper Colorado, Rio Grande and California regions and eliminate deficits in the Great Basin. Significant problems will still remain in the Lower Colorado basin and in California towards the end of the projection period even if demand drops 20 percent. Additional measures will be needed to assure reliable, long-term supplies for those areas.

If global climate changes and becomes warmer by an average of 2° C and precipitation declines by 10%, then deficits emerge immediately in southern regions in dry years and by 2020 to 2030 in average rainfall years. If global warming is delayed or the onset is not so sudden as assumed here (full effects felt by 2000), then the emergence of deficits and concomitant effects on fish and wildlife habitat and other instream uses will also be delayed. More definitive statements about the magnitude and timing of regional hydrologic effects in response to global climate change remain more a matter of conjecture than scientific fact, and will remain so until additional data becomes available to validate general circulation models.

The magnitude of anticipated deficits and a lack of credible measures for significantly boosting renewable supplies mean that measures to reduce demand become the focal point. Some measures to reduce demand are already being taken in response to market forces. When not planned, changes imposed by markets can lead to painful adjustments. Planned adjustments are often less painful to society. Now is the time to begin dealing with deficits if we are to avoid the environmental, economic, and social implications of deficits discussed in the next chapter.

NOTES

1. Ken Frederick suggested that the concept of shortages be clarified and contrasted with scarcities.

CHAPTER 6: ECONOMIC, ENVIRONMENTAL, AND SOCIAL IMPLICATIONS OF PROJECTED SUPPLY AND DEMAND

Economic, environmental, and social implications of continuing water use at projected levels are discussed in this chapter. Implications arise from two sources: projected shortages in supply and demographic changes. In the first case, implications help describe consequences of projections. Some readers may have difficulty envisioning how numerical statements of shortages will affect them. The discussion of implications can make the impact of the supply-demand situation more understandable and more personal. In the second case, demographic changes impact supply and demand even where supply shortages are not likely to occur before 2040. For example, population increases will cause increased growth in urban areas. Increased urban development has implications for water resources even though sufficient water supplies may exist.

IMPLICATIONS OF WATER SHORTAGES

The Rio Grande, Upper and Lower Colorado, Great Basin, and California water resource regions are projected to have water shortages of varying degrees by 2040. Water balances presented in Chapter 5 demonstrate that there are three alternative ways to balance water demands and supplies and avoid shortages. These are: 1) reduce offstream demands; 2) increase the level of groundwater pumping; or 3) reduce instream flows and accept degradation of fish and wildlife habitat. In each region, irrigation is the offstream water use responsible for more than two-thirds of water consumption. Irrigation is also the lowest valued offstream use in each region. Consequently, in reducing offstream demands, implications fall most heavily on the agricultural sector of the economy and society.

ECONOMIC IMPLICATIONS

Irrigated acreage in basins projected to experience water shortages amounts to about 5% of the total cropland acreage in the U.S. and about 14% of the total crop value. California contributes two-thirds of this value percentage from two-fifths of the acreage. Most irrigated acres in the other water-short regions produce relatively low-valued crops (Day and Horner 1987).

Implications for California

California produces more fruits, nuts, and vegetables than other regions. Over 200 different crops are grown commercially in the San Joaquin Valley with at least 125 of those contributing significantly to the food supply and economy of the nation. Five San Joaquin Valley counties which are heavily irrigated are among the nation's 10 highest producers of agricultural commodities on a gross value basis (San Joaquin Valley Drainage Program 1987). Water shortages in California, though infrequent, will cause significant price shifts for certain crops in certain seasons (e.g. winter lettuce and table grapes) where California irrigators dominate produce markets. Shortages will also cause significant changes in the quality of produce available.

The combination of price and quality changes may cause consumers to alter consumption patterns, foregoing certain products or purchasing substitutes. If consumers shift purchases, a ripple will be felt throughout the agriculture and food processing industries of California. These industries include fruit and vegetable processing, produce transportation, wholesaling and retailing, poultry and dairy processing, grain milling, cotton ginning, and processing of animal feeds. Thus, any changes in agricultural production will be greatly magnified in the California region.

Implications for the Southern Rocky Mountains

Water shortages in the Upper and Lower Colorado, Rio Grande and Great Basin regions affect crops of lesser value than those in California. Commodities produced under irrigation in these regions include wheat, corn, alfalfa, cotton, and rice. From a national perspective, irrigated outputs from these four basins are a relatively minor contribution to total supply. Consequently, water shortages in these regions will cause mostly local impacts. Producers in other parts of the U.S. where water is not in short supply can expand production to fulfill national market demands.

Hanchar et al. (1987) analyzed changes in irrigated acres and crop production resulting from shifts in exogenous crop production variables between 1976–1980 and 1981–1985. Between these periods, crop production costs increased as a function of increased energy costs. Average irrigated acreage declined in heavily-irrigated Arizona, Texas, and Oklahoma, with the termination of irrigation on some acres. Shifts that occurred between the two periods preview the shifts likely to occur when water shortages emerge in the Lower Colorado and Rio Grande basins. The key factor in this study was energy cost increases. In addition to increasing groundwater pumping costs, energy cost increases made other production inputs such as fertilizer and pesticides more expensive. Irrigators use more of these factor inputs than dry-land farmers.

Hanchar et al. (1987) reported that in Texas, Oklahoma, and Arizona, the area irrigated decreased by 1.9 million acres. In addition, cropping patterns did not change significantly. Grain crops, pasturage, and silage absorbed the bulk of the cuts. The implication of taking most production cuts in livestock feedstuffs is that the regional livestock industry will bear the brunt of any cutback in irrigated acreage.

In New Mexico, the area irrigated increased 78,000 acres or 9% . More importantly, cropping patterns changed significantly. Grain crops, pasturage, and silage showed minimal change. However, cotton acreage rose 7%, oil crops acreage rose 100%, and fruit, nut, and vegetable acreage rose 530% . The obvious shift was to higher-valued crops. California showed a similar shift to irrigating higher-valued crops as pasture and silage acreage dropped about 20% while cotton acreage rose 30% and fruits, nuts and vegetables rose 17%.

To the extent that farmers can shift production to higher-valued crops as irrigation becomes more expensive due to higher water costs or shortages, they can cushion the economic impact of the decline in acreage irrigated. However, the potential of the economy to absorb additional supplies of higher-valued products is not unlimited. To the extent that export markets for these commodities can be developed, farmers can expand beyond limits imposed by demographic changes in the U.S. population.

The Department of Agriculture (1987) projected that irrigated acreage will decline by 19 million acres by 2030. The Appraisal outlined several factors expected to contribute to the decline including advances in technology, increases in crop yields from genetic improvements, higher costs of production in water-short areas, and elimination of price support systems. In areas where water shortages are projected for this Assessment, significant economic impacts on suppliers of farming inputs are expected as irrigated acreage declines.

Several statistics from the Appraisal about irrigated farms illustrate the potential impact for farm suppliers. Compared to the average dry-land farm, the average irrigated farm has 2.5 times more money invested in land and buildings, twice the value in machinery and equipment, 4 times the value of crops, 2.3 times the value in livestock sales, twice the fertilizer requirements and triple the pesticide requirements. Irrigated farms use more than 3 times the energy, 5 times the labor, and 7 times the specialized contract labor. Each acre of irrigated land converted to dry-land farming will cause impacts on bankers, equipment dealers, farm supply businesses, agricultural chemical suppliers, fuel and electricity suppliers, farm laborers, and contractors.

ENVIRONMENTAL IMPLICATIONS

Reducing offstream demands by reducing irrigation in areas projected to experience water shortages will create additional environmental problems primarily related to salinization. The alternatives of increasing groundwater mining or tolerating a reduction in fish and wildlife habitat and recreational use of surface water sources also have environmental consequences.

Salinization

Salinization is a problem in arid and semi-arid areas where precipitation is insufficient to leach salts from the soils. If soil moisture around plant roots contains too much salt, most crops cannot absorb the water and nutrients needed to germinate and grow. Saline (excessive salts, mainly chloride and nitrate) and sodic (excessive sodium) conditions are lowering productivity on 10% of the nation's crop and pasture land, including nearly one-fourth of all irrigated crop and pasture land. Six western water resource regions have salinity and/or sodicity problems on one-third or more of crop and pasture land according to the Appraisal. Notable areas where salinity is increasing are southern California, the lower Gila River basin, Arizona (major tributary to the lower Colorado River), and parts of the Rio Grande basin in southern New Mexico and west Texas. These are all areas where water deficits are projected to increase.

Saline conditions in soil are remedied by applying a sufficiently large amount of water to the soil to leach the salts out of the plant root zone. Salts are either carried to aquifers and to streams or run off overland directly to streams. Salts are not neutralized or bound in any sense, but merely moved off-site, typically in dissolved form. As water shortages emerge as a significant problem in areas where salinization is also a problem, less water will be available for leaching. Less water will also be available in streams to dilute and carry dissolved salts away. Farmers further downstream will have saltier water for their irrigation supply. As water shortages emerge, salinity will increase in importance in the five water resource regions.

Salinity occurs naturally in many western regions. About half of all salinity in the Colorado River at Hoover Dam is attributed to natural sources, and the remainder comes from water use. Of the salinity attributable to water use, three-fourths comes from irrigation (Colorado River Water Quality Office 1986). In headwaters on national forests in north-central Colorado, the salinity concentration of tributaries to the Colorado River is only about 50 parts per million. At Imperial Dam, near the border with Mexico, salinity concentrations fluctuated between 608 parts per million in 1986 after record high flows flushed and filled the major reservoirs on the Colorado River and 826 parts per million in 1982. Without control measures, salinity is projected to increase to more than 1000 parts per million at Imperial Dam by about 2010 (Colorado River Water Quality Office 1986). The Environmental Protection Agency's public drinking water standards limit total dissolved solids (of which salinity is a component) to less than 500 parts per million. Consequently, water withdrawn for municipal use from the lower reaches of the Colorado River must be treated by expensive desalinization processes to render it potable. The need for and cost of doing so will increase as salinity concentrations increase.

Agricultural losses, either as lower yields or higher production and management costs, begin when salinity concentrations in irrigation water reach 700 to 850 parts per million, depending on the soil type and crop. Excessively saline water causes scours, staggers, and occasional blindness in livestock. Excessive salinity in water makes it unfit fish habitat and damages riparian vegetation used for wildlife habitat.

Salinity causes both on-site and off-site damages. Irrigation water return flows carry salinity off-site. The Colorado River Water Quality Office (1986) estimated that off-site damages in the Colorado River Basin alone total $580,000 for every 1–part-per-million increase in salinity concentration at Imperial Dam. About 5% of that damage estimate is a direct cost to agriculture, about 25% is damage to the regional agricultural economy, and the remaining 70% is damage incurred by municipal and industrial users.

Much of the increased salinity in the Lower Colorado region resulted from using irrigation practices requiring large amounts of water, such as overland flow and flood irrigation, in locations with naturally-saline soils. Adoption of water-conserving irrigation practices in response to rising water prices may be an effective means of reducing saline discharges from farmland.[1]

A coordinated program for salinity control in the Colorado River Basin was developed by federal agencies of the Departments of Interior and Agriculture and EPA and agencies of the states comprising the basin. The program treats salinity as a nonpoint source of pollution. Control measures are designed to prevent 1.3 million tons of salt annually from entering and mixing with the river's flow. Similar approaches to those applied in the Colorado River basin can be used in other basins when the interaction of saline soils and water shortages creates problems.

In the San Joaquin Valley of California, related problems with irrigation return flows emerged. Specific salts such as selenium were concentrated in irrigation drainage water and caused significant health impacts to waterfowl. Selenium can bioaccumulate in the food chain, as demonstrated by waterfowl impacts. Further, low levels of selenium are essential for humans, yet slightly higher levels can be toxic. These factors have elevated concerns about the safety of food grown in the San Joaquin Valley. Recent research shows that not enough selenium is being added to the parts of crops destined for human consumption to cause changes in diet (University of California, Davis 1988). However, levels of selenium in some farmland areas in the western San Joaquin Valley are high enough to justify careful monitoring. Further, efforts to solve the saline irrigation return flow problems for the valley, and particularly at Kesterson Reservoir, will be costly because of existing biologically concentrated levels of selenium. High values of agricultural commodities produced in the valley means that considerable expense may be incurred to deal with the problem (San Joaquin Valley Drainage Program 1987). A total of $38.5 million in state and federal funds was spent on the program in fiscal years 1986 and 1987.

Groundwater Mining

Mining of groundwater occurs when the rate of water use exceeds the rate of aquifer recharge. As with other stock resources such as metallic ores, groundwater mining is socially acceptable so long as the rate of extraction is economically efficient and does not cause adverse environmental consequences.

Groundwater levels are currently declining from 6 inches to 5 feet annually beneath 14 million acres of irrigated land in 11 western states where groundwater is the principal irrigation source. Pumping costs are rising, well yields are declining, and pumping efficiencies are decreasing. In these areas, municipalities and rural residents rely on groundwater for domestic and livestock supplies. As groundwater levels have dropped, competition among water uses has emerged.

Sloggett and Dickason (1986) describe the agricultural sectors most affected by recent groundwater level declines. Rice producers in Arkansas and Texas, citrus producers in Florida, and grape producers in California are those most severely impacted by recent groundwater declines. Since the mid-1970s, more than 2 million acres in the Texas High Plains have converted to dry-land farming because of increased irrigation costs associated with pumping groundwater from greater depths. Shifts in crop production, such as converting irrigated cotton, corn, or alfalfa fields to dry-land grain sorghum or wheat production, have affected growers of the same crops in other U.S. regions. As prices rise or fall in national markets in response to decreases or increases in regional and national commodity supplies, some farmers will gain and others will lose.

New irrigation technologies are often touted as the way to extend aquifer life. New technologies improve water delivery efficiencies. For example, newer equipment operates at lower pressures so less water is lost to evaporation between the irrigation nozzle and the ground. However, adoption of new technologies has not always resulted in reduced water consumption. Often, farmers continue to use the same volume of water but irrigate more acres (Sloggett and Dickason 1986). Supalla et al. (1982) studying the Ogallala aquifer area found that increased water efficiency nearly eliminated the increased cost of pumping. Thus, the immediate effect was no change in irrigated acreage.

State and local governments have exerted regulatory control over the groundwater mining issue in some areas. Recent passage of laws and ordinances restricted further irrigation development in about 45% of the irrigated area affected by groundwater mining. Sloggett and Dickason (1986) and Supalla et al. (1982) both concluded that there is no region-wide problem of groundwater mining to 2020. Any problems occurring before then will be localized.

Social implications of groundwater mining are related mainly to prospective ways of augmenting supplies or to the effects of limiting demands. Increasing supplies using interbasin transfers is both politically infeasible and uneconomical in the Great Plains; managing available groundwater is the only option. Interbasin transfers have been more acceptable in the Colorado River basin—both Denver and southern California use them.

Concerning methods of reducing demand, Supalla et al. (1982) found that farmers prefer to have demand management focus on education and information about new research findings. The farmers' preference is to allow pumping costs and crop prices to manage demand.

Other water users prefer demand management that focusses on mandatory restrictions in irrigation water use. Supalla et al. found that mandatory restrictions would cause a 3% reduction in projected economic *growth*. Average annual growth of 3.65% without mandatory restrictions would fall to 3.59% annual growth with restrictions. These authors also reported that reductions in economic growth of this magnitude were not acceptable to agricultural interests. These differing points of view illustrate some of the social implications of groundwater mining.

Fish and Wildlife Habitat

Discussions on acid deposition and erosion in Chapter 2 outlined the effects of these externalities on wildlife and fish habitat. Excessively acid surface water affects biota low in the food chain and interferes with reproduction and development of fish and wildlife. Erosion results in sediments in streams and also interferes with reproduction and respiration.

Water supply shortages discussed in Chapter 5 will have adverse effects on instream flows and habitat for fish and wildlife and recreation dependent upon adequate flows. The salinity discussion in this chapter mentioned fish and wildlife effects of saline drainage, especially in the San Joaquin Valley.

Flather and Hoekstra (1989) discuss effects of low flows and poor water quality on fish and wildlife in additional detail in their companion report on wildlife and fish.

SOCIAL IMPLICATIONS[2]

Population

Population distribution would be strongly affected by water shortages. While it remains for the 1990 Census to reveal whether or not rural areas are continuing to grow faster than urban ones—a trend first reported in 1980—growth would be limited in those areas lacking either sufficient water supplies or delivery structures. Minimum lot sizes of 10 to 35 acres are used in some western areas to limit development of groundwater for rural livestock and domestic supplies. The Southeast is likely to experience growth rates even higher than current levels as people and industries choose to move where water is plentiful. Additionally, those northeastern and midwestern areas which would no longer experience the population decline that occurred in the 1970s and 1980s would need to provide social and environmental services demanded by a growing population.

Water treatment to assure reliable supplies and wastewater treatment to avoid environmental degradation are two key services affected by shifting population growth trends. Much of the infrastructure for water treatment and delivery in the northeastern and midwestern states is old. The combination of repair, replacement, and expansion will tax capabilities of many municipalities. Many small towns did not participate in the EPA wastewater treatment construction grant program established by the Clean Water Act because their discharges were below minimum levels necessary to qualify. However, towns were not relieved of the burden of meeting the discharge regulations. So in the future, they will be faced with upgrading facilities and adding additional capacity using loans instead of grants.

If more growth occurs, limited financial resources will be stretched to the point where major rate increases are the only way to garner the necessary construction funding.

The population composition would also change if water shortages become prevalent in an area. Fewer people would move into an area with water shortages so the resident population would stabilize according to prevailing characteristics. However, if wealthier, more mobile, younger people move to areas with more secure water supplies and accompanying economic opportunities, communities they leave will experience an increase in the proportion of poor and elderly—groups with fewer relocation options. As the remaining population ages, public services demanded will also shift. Precedents for the kinds of shifts likely to occur are found in cities that relied heavily on iron and steel production from the 1930s to 1950s. Shifts in population composition that occurred as a result of changes in the steel industry are similar to shifts likely to occur if projected water shortages materialize in western agricultural areas.

Attitudes, Beliefs, and Values

These social indicators reflect challenges posed by water shortages. If shortages become prevalent, residents will spend more time and money securing water and an overall decline in quality of life will likely occur. Concurrent declines are expected in the American "can do" attitude as well as individuals' perceptions that they have a degree of control over their future. Municipalities and business water users are expected to respond to shortages by raising water prices and ultimately buying irrigation water rights. The social impact of such transactions is a weakened tie to the land—a major factor in rural agrarian lifestyles, especially on western family farms.

Any social analyses of prospective changes in water use and management should incorporate three basic kinds of information. First, the analyses should recognize that attitudes, beliefs, and values vary by population cohort and background. Second, the analyses should use marketing survey techniques and other sociological instruments to elicit attitudes, beliefs, and values about proposed changes in water use and management by cohort. Third, political polling techniques should be used to evaluate the likelihood that specific cohorts will vote in certain types of elections or take other action, such as seeking injunctions or pursuing litigation. In this way, information on social implications of resource use changes can be gathered and used by decisionmakers when evaluating alternative management strategies. Too often, such analyses are done only after decisions are

made; wise stewardship of natural resources suggests they should be done beforehand.

Social Organization

Institutions in communities experiencing water shortages would be affected in a variety of ways. If expected population decreases materialize and competition for water increases, local governments will be required to increase their level of technical and political knowledge of water supply issues such as regulation/enforcement/litigation, and negotiation/consensus-building skills. Gaining knowledge about sophisticated water-related technology and conservation programs and developing the ability explain the necessity for and consequences of the technology and programs to different audiences with a variety of technical backgrounds will also become crucial.

Internal conflict between agencies committed to water quality and those fostering economic growth will increase. Tools of government such as enforcement of regulations and ordinances and eminent domain and annexation would assume greater importance. Officials such as county extension agents may assume positions of leadership in implementing technical and complex changes in resource use.

Local governments would be required to address other challenges caused by water shortages. Growth in the proportion of elderly and poor cited earlier would probably increase demand for social services such as health care and income assistance. Conversely, the amount of tax revenue available to communities to pay for such services will decrease as the younger, more affluent sector moves away. Property tax revenues would go down as farm property values decline due to reduced productivity in dry-land agriculture compared to irrigated agriculture. The lack of sufficient water to attract additional jobs may also lead to reductions in residential property values. Sales tax revenues would also reflect a reduction in the number of homeowners who would ordinarily make major purchases associated with moving into an area. Income tax revenues would also decrease due to the lower number and smaller size of taxable incomes.

Competition among interest groups would also be likely to increase as shortages become more prevalent, encouraging polarization among community members. Examples of groups likely to be affected are recreationists (anglers, boaters, hunters), ranchers, real estate and landscaping concerns, and high-tech industries dependent on water quality. How to satisfy competing demands for water use would be the water managers' challenge.

In many cases, western state and local governments are seeking to diversify local economies by attracting industries that produce no air or water pollution or that depend on clean water for production processes. New industrial developments, lured by tax breaks and relocation assistance, bring new jobs to an area and jobs attract people. Often, new jobs are filled by people from other areas; people whose attitudes, beliefs, and values about resource use are different from those of long-time residents. Clashes that typically emerge over future resource uses in such settings are often "strawmen" for differences in attitudes, beliefs, and values among newer versus older residents. The ballot box and the electorial process are the traditional means of settling many of these disputes. Officials elected under such circumstances should be sensitive to maintaining or rebuilding community cohesion.

Land Use Patterns

If water becomes less available and more expensive, agricultural operations dependent upon irrigation will either change to dry-land farming or cropland will revert to native vegetation. In many areas where water shortages are projected, native vegetation is range grasses or shrubs.

The major reason why agricultural land goes out of production in response to water shortages is that landowners can obtain a higher economic return by putting land and water to another use including leaving it idle.[3] In the 1800s, before the advent of inorganic fertilizers and farming practices that conserved soil, land was farmed until the natural soil fertility was exhausted and then abandoned. For example, cropland abandonment in the South from the 1880s to the 1950s and its subsequent reversion to native vegetation, southern pine forests, was one principal factor behind the rapid expansion in the southern forest products industry following World War II. When cropland moves out of agricultural production, most will likely not return to crop production. The Appraisal projects 160 million acres of cropland will be idled by 2030.

Cropland will also go out of production for reasons other than inadequate returns to farming. Some will shift to urban and suburban uses. Of the agricultural land going to urban and suburban uses, 63% will come from cropland, 18% from pasture, 13% from forest, and 6% from other agricultural land such as orchards. The Appraisal notes that 80% of cropland likely to move to nonagricultural use by 2030 is prime farmland. The reason prime land is most likely to go to urban uses is that settlements often began in the center of fertile areas to provide goods and services to farmers. As these settlements grow, the expansion erodes the prime cropland base.

Much prime agricultural land is river bottom land. Many agricultural settlements began along streams because waterways provided transportation and waterpower used to process crops.

As river bottomland use moves from agriculture to urban uses, water-related impacts result. Periodic flooding of river bottom cropland is what enhanced the fertility of the land, making it prime agricultural land in the first place.

The major implication of expanding urban development on flood plains is that these areas will periodically be flooded and suffer economic damages. The land use implication is that additional flood protection measures will be needed. Structural flood protection measures alter

natural stream channels, change ecosystems, and create environmental changes. Non-structural flood protection measures now in vogue often have adverse social consequences. Landowners may perceive that zoning and other non-structural measures are infringing upon their rights and diminishing the land development values. There is no way to avoid implications of one sort or another when expanding development, particularly on flood plains.

If water shortages become more prevalent, so will zoning use as a means of regulating growth. An increase in zoning is liable to prove particularly contentious. To a large extent, the West was settled by people who strongly valued personal freedom. Concepts of homesteading and building wealth from scratch through land resource utilization—appropriating public domain land for use in ranching, farming, mining, logging—created the still-prevalent attitude that government exists mainly to guarantee personal rights. The use of government zoning powers to avoid "the tragedy of the commons" is only now emerging in the West. This development, while common in New England as early as the 1700s, runs counter to the heritage and established social organizations of many small western communities. As resource use conflicts grow, social organizations in the West are likely to evolve in a manner similar to their eastern predecessors. Over time, one would expect the West to become more "liberal" in the sense of the populace agreeing to subordinate personal goals for promotion of the common good.

Another land use impact of water shortages is that water-related recreation will be curtailed due to lack of water. Water access and use points—beaches, riparian camping areas, and boat launching areas—will become more lightly used. Further, recreational quality will probably decline. For example, more mud flats will be exposed and debris on channel bottoms may become a hazard to boaters and water skiers. Use during dry seasons may cease altogether. Concern over conserving remaining water may result in restricting access to key watersheds to avoid damage such as by wildfire or by giardia infestations in water.

The importance of public forests, rangelands, and wetlands on all ownerships will become more apparent as water shortages emerge. Chapter 4 outlined the current trend in wetlands area. Unless this trend is reversed, waterfowl populations will become increasingly endangered. Recreation related to wetlands, particularly fishing for finfish and shellfish and waterfowl hunting, will diminish in quantity and quality—social impacts of considerable importance to anglers and hunters. Support for the continued existence and possible expansion of wetlands will increase.

Summary

Without modification of current rates of growth in water demand, large areas of the West are projected to face water shortages early in the 21st century. These areas need to implement technological and behavioral changes without delay if they are to ensure a continuous water supply without further degradation of fish and wildlife habitat or groundwater mining.

SUMMARY

In this chapter, the environmental, social, and economic implications of the current and projected supply-demand situations for the water resource and water users have been reviewed. Projections developed and compared in Chapters 3, 4, and 5 are based on recent trends in water use and management from 1960 to 1985. The goal was to describe what the water use situation will be in 2040 and its concomitant environmental, social, and economic implications if society does not change recent patterns of water and related land resource use. Major implications are:

- Water shortages will become prevalent in the California, Upper and Lower Colorado, Great Basin, and Rio Grande water resource regions.
- Water shortages will increase the food cost for humans and livestock. Substantial price increases can be expected for products such as vegetables, fruit, and nuts, particularly in dry years. To the extent that production of livestock feed and livestock production cannot be shifted to other U.S. regions, prices of red meat (primarily beef and mutton) and related livestock products (such as wool) will increase. The price of cotton products will also increase if cotton production cannot be shifted from the Southwest to other parts of the U.S.
- Water shortages will disrupt local economies, especially those relying heavily upon irrigated agriculture and the processing, sale, and transportation of crops and products grown under irrigation.
- Water shortages will cause major social impacts on local residents and their communities.
- A continuation of recent trends will lead to groundwater mining.
- A continuation of recent trends will reduce wildlife and fish habitat and other instream uses such as recreation.
- Continuation of recent trends in water use will lead to increased salinity, thus causing additional disruptions in local economies relying upon surface water sources for potable supplies. Salinity will adversely affect farmers depending on irrigation water.
- Continuation of recent trends in wetlands conversion will lead to significant additional reductions in waterfowl populations and reduction in fishing, hunting, and other recreational benefits.
- Expansion of urban areas will increase at the expense of prime agricultural land.

These projections and their implications are only "most likely" in the sense that if society makes no changes in water use patterns, then the projections are most likely to be realized. Many implications of continuing recent water use trends describe a painful transition in lifestyles to 2040, especially in the southern Rocky Mountains and California.

The good news of this Assessment is that we have an opportunity to change the way water has been used in recent years and avoid many of the adverse implications described in this Chapter. Many changes have been made in water use since the 1972 passage of the Clean Water Act. That was strong medicine for our water quality problems but we needed it. More changes in water use are called for; many will call for taking some pretty strong medicine now to avoid major future problems. Whether the nation chooses the distasteful medication now or chooses to tolerate the disease's pain later is uncertain. The painful future consequences of the nation's addiction to cheap water and waste disposal were described in this Chapter; medication and its consequences are described in the following chapters.

NOTES

1. I am indebted to Ken Frederick for suggesting this approach to reducing saline discharges.

2. This section was prepared by Susan Johnson, Sociologist, who is a member of the RPA Staff.

3. Some current agricultural programs pay farmers for idling land previously used for growing certain crops.

CHAPTER 7: OPPORTUNITIES TO IMPROVE THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

The objective of this chapter is to highlight the most significant opportunities available for improving the management of water and related land resources. Implications of water shortages discussed in Chapter 5 provide many opportunities for altering annual crop production practices to avoid adverse environmental, social, and economic impacts. Opportunities whose primary application is to crop and pasture land have not been addressed here. In this chapter, the focus is narrowed to matters of interest to forest and range managers.

Opportunities presented are all high-priority; the order of presentation here does not reflect a ranking. Opportunities were selected without regard to who should implement them. Some are opportunities for both private groups and public agencies. Some opportunities requiring government involvement are opportunities for federal, state, or local agencies. The common thread is that the opportunities all pertain to forests and range management. The opportunities to be discussed are:

- Ensuring suitable flows for instream water uses emphasizing fish and wildlife habitat and recreation;
- Improving watershed condition with special emphases on maintaining water quality, managing the timing of runoff, improving riparian areas, and enhancing soil productivity;
- Encouraging use of non-structural watershed improvement measures to avoid flood damages;
- Implementing nonpoint-source pollution abatement approaches for silvicultural and range management activities; and
- Reversing the trend of losing wetlands.

ENSURING SUITABLE FLOWS

The water budget analyses of Chapters 4 and 5 reveal that when deficits occur in the Lower and Upper Colorado, California, Great Basin, and Rio Grande water resource regions, projected low flows will be insufficient to provide good survival habitat for fish, wildlife, or recreation. Population dynamics for most fish and wildlife species are such that having poor survival habitat for an extended period an average of one year in five is too frequent to provide sustained high-quality fishing and wildlife-related experiences.

Projections indicate that the situation will worsen in proportion to increases in demands for offstream surface water use. In regions where water shortages are projected, many rivers originate on public lands, thus public land managers have opportunities to pursue management practices that augment instream flows. Through administrative procedures, managers can help ensure protection of minimum instream flows. These opportunities can be realized by manipulating vegetation to augment low flows and protecting instream uses through administrative controls and state water rights procedures.

OPPORTUNITIES TO MANIPULATE VEGETATION TO AUGMENT LOW FLOWS

Research demonstrates that timber harvesting patterns and frequencies can be planned to increase water yield from some sites. Most increases come from the fact that timber harvesting reduces evapotranspiration. A second benefit is that if cutting patterns are properly planned, residual stands will trap and concentrate drifting snow in partially-cut areas much as snow fences are used to trap snow and keep it off roadways. Cutting intensity can be designed so that effective trapping occurs and enough shade is provided to retard melting in early summer. Thus, the snowmelt period is extended and high springtime peak flows are reduced. The main effect of this practice is make more meltwater usable.

Troendle (1983) concluded that with prudent management of high-altitude subalpine forests in the Rocky Mountains, an increase of 0.1 to 0.25 acre-foot per acre in water yield can be realized. By altering the forest's aerodynamics and energy budget, timber harvest alters the accumulation and melt characteristics of the snowpack. These impacts are partially translated into flow changes. Eliminating vegetation reduces evapotranspiration losses which also translate into increased flows. Because vegetation recovers after cutting and its evapotranspiration increases, only one-fourth to one-third of the acreage under this kind of management will produce increased yields due to reductions in evapotranspiration at any one time. The potential for increasing water yield is greater in the northern than in the southern Rocky Mountains, but areas in the Upper Colorado and Great Basins are amenable to these vegetation management practices.

Douglas (1983) concluded that water yield from well-stocked northeastern forests could be increased from 0.3 to 1.0 acre-feet per acre the first year after clear cutting. As the forest grows back, water yield drops logarithmically back to base levels. Increased yield duration averages 1.9 years for each 0.1 acre-foot of increase. There are two problems with applying these research findings. First, diversity of landownership and ownership objectives makes capturing the full potential increase nearly impossible because of difficulty in coordinating cutting patterns. Second, many stands in the northeast are understocked and they have less potential increase in water yield because they are not currently at maximum evapotranspiration. Douglas concluded that the greatest potential for increasing water yield is on municipal or utility watersheds. Even here, timber sale revenues will often dictate cutting patterns rather than increased value of the extra water produced. In short,

Cutting patterns and orientation can affect snowmelt. This 66-foot wide clearcut strip runs east-west. By early April, all snow has melted on the north edge while 25 inches remain on the south side.

Douglas concluded that we know how to increase water yield in the northeast but until shortages occur, there is no incentive to implement research findings.

If sufficient reservoir storage existed to contain all springtime runoff, it would not matter when snow melted. All meltwater could be captured. It could then be metered into streams during dry periods to maintain adequate low flows and good survival habitat. Sufficient storage does not exist, however, and sites for building additional reservoirs are scarce and rarely feasible either from environmental or economic efficiency perspectives. Thus, structural solutions to problems of maintaining adequate low flows do not appear promising. Vegetation management practices, on the other hand, offer some promise for lengthening the runoff period and shortening periods of low flows which create problems for instream water uses.

OPPORTUNITIES TO ENSURE WATER NEEDED TO SUPPORT INSTREAM USES

In some states where the appropriation doctiine is used, stream water is oversubscribed in drier years when not enough water is available to meet all users needs. Instream water uses are not recognized as a beneficial use for water appropriation in many states; where they are recognized, they are defined as junior to other uses. In such situations, instream water uses are foregone to satisfy other uses. Thus, there is little opportunity to ensure instream flow rates which provide, at a minimum, good survival habitat and recreation.

Residents of western states have begun to recognize the importance of maintaining instream flows and benefits created. Institutions are beginning to respond to public sentiment on these issues. The current situation is a dynamic one; change is underway. However, many more opportunities remain to be captured beyond those already obtained by recent changes. There is strong support from anglers, hunters, and recreationists for increasing and enhancing fishing, wildlife, and instream recreation experiences. The land manager has an opportunity to use the support of groups advocating maintenance of suitable flows to help influence how instream flows are protected. Partnerships thus established often provide opportunities for addressing other land management issues.

IMPROVING WATERSHED CONDITION

Fundamental concepts of watershed condition and its relationship to water quality and quantity were outlined in Chapter 2. The percentage of watersheds in the lowest condition class, those needing major capital improvements to regain productivity and produce top-quality water, varies between 13% (South) and 25% (North). Watersheds in this Investment Emphasis class typically have vegetation and soils that have experienced significant disturbance. Often, vegetation is sparse or lacking and much of the soil surface is exposed to the direct impact of precipitation. In such situations, runoff water quality is rarely up to the level displayed in Table 13.

Water supply utilities, whether public or private, have long emphasized maintaining high-quality supplies. In areas where the riparian doctrine of water use is in force and surface waters are the supply, utilities have sought to acquire land adjacent to streams and reservoirs and restrict trespass. The objective has been to minimize the potential for water contamination. Utilities viewed this approach as less expensive than installing water treatment processes to purify the water.

In areas where the appropriation doctrine of water use is in force, municipal water utilities have taken their place in the queue of water users. Over time, and especially west of the Great Plains, utilities have become less confident of having adequate supplies. Further, increasing amounts of dissolved salts and nutrients in surface waters reduce its potability in many places. Therefore, western utilities are beginning to compete for water, often seeking to purchase more-senior rights from agricultural interests. The utilities' goal is to divert water nearer its source which means the supply will be of more reliable quantity and higher quality. It matters not whether utilities are operating under the riparian or appropriation doctrines, there is increasing emphasis on securing and maintaining high-quality surface waters.

INCREASED EMPHASIS ON MAINTAINING WATER QUALITY

Land management consequence of utilities' search for reliable, high-quality surface water supplies is that utilities will become much more interested in watershed management activities upstream. In coming years, utilities will exercise critical scrutiny over those activities that disturb ecosystems and increase salts, sediments, or other pollutants moving into streams. If there is an increasing trend in those activities in watersheds producing potable supplies, then utilities are expected to become vigorous participants in the planning, review, and environmental analysis process of watershed managers. In such circumstances, utilities and other water users dependent on high-quality water will become effective advocates for mitigating ecological disturbances. In addition, there will be interest in rehabilitating areas where previous disturbances are contributing to in-stream water quality degradation.

INCREASED EMPHASIS ON MANAGING THE TIMING OF RUNOFF

Vegetation management activities discussed as a way of ensuring suitable flows, represent one of three opportunities for managing runoff timing. In addition to using timber harvesting patterns to trap snow, snow fencing can be erected to concentrate blowing snow in drifts and prolong melting into early summer. Snow fencing, on a scale much greater than the woven wooden lath typically erected along roads in the East, is particularly useful for trapping snow in cirques above timberline and on high-altitude rangeland.

Weather modification, primarily cloud seeding, can be used to increase snowfall on watersheds. Used in conjunction with vegetation management and large-scale fencing, opportunities exist to store considerable amounts of snow in drifts to prolong melt.

Currently, snow melt occurs in the headwaters of water-short regions in April to early June. Storage reservoirs fill early with meltwater. Because snowmelt occurs when crop irrigation needs are low, water that cannot be stored moves downstream underused. In July and August when irrigation and other offstream and instream water needs are high and instream flows have declined, water stored in reservoirs is released to help meet needs. The objective of trapping snow and delaying snowmelt is to extend meltwater runoff into early summer to help meet emerging summertime water needs. The result is that the beginning of reservoir drawdown can be delayed, thus making more water available in late summer and early fall when instream flows and needs are greatest.

It has not been determined if enough snowfall can be trapped to prolong melting into July and make a significant contribution to regional instream flows. The challenge to watershed managers is to determine if these three approaches—vegetation management, snow-trapping structures, and weather modification—can be combined to significantly influence the timing of water availability.

INCREASED EMPHASIS ON IMPROVING RIPARIAN AREAS

Riparian areas—the strip of land and vegetation bordering a stream or lake—are the last line of defense against pollutants reaching streams and lakes. These areas are also the primary buffer between land management activities and adverse effects on fish, wildlife, and other organisms that are a part of the aquatic ecosystems.

Riparian vegetation often shades streams and keeps water temperatures cooler and more amenable to fish and other aquatic organisms. This vegetation also provides cover for wildlife. Recent research demonstrates beneficial effects of allowing riparian vegetation debris to modify stream channel configurations and augment cover and structure normally provided by rocks and boulders. Riparian vegetation also slows precipitation runoff, thereby reducing peak flows during high flow

periods. Although riparian vegetation consumes water, the benefits it provides far outweigh the value of the water it uses.

Emphasis on maintaining water quality will also manifest itself in an increasing concern over safeguarding riparian areas. Mechanized equipment use, heavy livestock grazing, or other activities that disturb riparian vegetation will be increasingly viewed as unacceptable resource management. Active programs to assist the recovery of riparian vegetation damaged by trespass or overuse are needed in many watersheds in the Investment Emphasis condition category.

OPPORTUNITIES TO ENHANCE SOIL PRODUCTIVITY

Soil productivity refers to a soil's ability to produce vegetation. The concept of soil productivity includes all chemical, biological, and physical aspects of a soil that affect its ability to sustain vegetation production over time.

Many factors discussed in Chapters 2 to 6 influence soil productivity. For example, erosion results from physical practices such as soil disturbance or vegetation removal that lead to topsoil moving off-site. Sediments carry nutrients away, thus reducing the site's ability to sustain vegetation at previous levels. Acid deposition affects soil chemistry by making aluminum ions more mobile and altering nutrient relationships, both of which lead to reductions in soil productivity.

When treating watersheds in the Investment Emphasis class, opportunities exist to affect more than the physical aspects of the site, such as halting erosion. Treatments should be designed that also consider the chemical and biological aspects of soil productivity. Chemical considerations include restoring nutrient balances such as by fertilization or inclusion of legumes in revegetation plans. Biological considerations include maintaining and enhancing biological diversity by restoring a mixture of native species instead of using only monocultures or exotic varieties. Site analyses for planning watershed recovery investments need to examine all aspects of soil productivity so the root cause of the problem can be cured instead of only treating symptoms.

SUMMARY

Increasing emphasis on maintaining high water quality, reliable stream flows, and diversity in fish and wildlife populations presents a significant opportunity to build a consensus for improving watershed condition. Improvements needed include rehabilitating watersheds and riparian areas, restoring soil productivity, and reducing adverse water quality impacts. Consensus will take the form of increased demand to restore adequate vegetation to watersheds, especially riparian areas, and to hold sediments and nutrients in place.

Adherence to nonpoint-source pollution regulations and use of Best Management Practices will be supported by water users as a way of encouraging rehabilitation and restoration of problem watersheds. Even though cities served by water utilities may be geographically distant from watersheds needing work, strong support of city governments and utilities for improving watershed conditions will be experienced. Forest and rangeland managers should recognize that this consensus is emerging and plan proactive ways of using the opportunity to help achieve rehabilitation and restoration goals.

Where watersheds are in middle-class or Special Emphasis condition, integrated resource management is the primary vehicle for facilitating additional watershed rehabilitation or preventing additional degradation of sensitive watersheds. The opportunity afforded by increased attention to maintaining water quality and altering runoff timing also provides additional support for managing these areas. For example, use of interdisciplinary teams to develop environmental assessments and prepare management prescriptions for watersheds in the Special Emphasis class will be a primary vehicle for maintaining and improving watershed condition. Included in this is an increased emphasis on seeking coordinated multi-disciplinary approaches to managing riparian areas. Special attention will be needed to address the resource characteristics making the watershed especially sensitive to use.

Watershed researchers can use these opportunities to create support for developing and testing innovative ways of protecting watersheds and riparian areas from degradation, and for accommodating multiple uses. Involving watershed researchers in resource planning and taking advantage of their findings to mitigate adverse impacts will become increasingly important.

Contributions of watershed specialists toward making other resource uses feasible by mitigating detrimental watershed impacts have often been overlooked in the past. The increased attention that will be devoted to maintaining water quality and riparian areas will result in more accurate accountability for successes in watershed rehabilitation, restoration, and management.

NONSTRUCTURAL FLOOD DAMAGE REDUCTION

Society has three general ways of responding to flood damages. One is to provide direct economic relief to those suffering losses. The Federal Emergency Management Agency (FEMA) coordinates government responses to flood disasters. Grants and low-interest loans to residents as well as direct recovery measures to restore infrastructure (e.g. roads, bridges, electricity, sanitation) are examples of the services delivered by FEMA. A second response is to build structural measures designed to control flood waters. These include dams, dikes, levees, floodwalls, diversion structures, and channel alterations. The third way of responding to flood damages is to use nonstructural measures to reduce flood peaks and the potential for flood waters to damage investments. Forest and rangeland managers have opportunities to participate in the latter approach through watershed management.

FLOOD DAMAGES IN RURAL AREAS

The bulk of flood damages—60% to 70%—occur in rural areas, largely to agricultural investments. Although urbanization is increasing, rural damages are still projected to account for half of annual damages in the next century. Most damage is to crops and improvements on flood plains with fertile soils. As agricultural land use shifts occur, these sites will be among those where crop production will become more concentrated. Flood plains are also often used for grazing. Improvements subject to flood damage include fences and structures, such as watering facilities and shelters. In mountainous terrain, stream bottoms are common locations for roads and utility lines. These too are susceptible to flood damages, even when properly designed and constructed.

Another method of curtailing flood damages is limiting construction and other flood plain developments. Flood plain zoning was introduced several decades ago along with the federal flood insurance program as a method of regulating flood plain encroachment. While the insurance program has been successful, the zoning program has been less so. When the government is willing to provide low-cost insurance, landowners are content to continue developing flood plains.

OPPORTUNITIES TO REDUCE FLOOD DAMAGES

Floods occur when precipitation is heavy and infiltration rates are less than precipitation rates. Thus, rainfall runs rapidly over the soil surface and into streams. Because forest and rangeland managers have little control over precipitation patterns, frequency, or intensity, focus of flood damage reduction efforts must be on the two key points of maintaining soil infiltration rates and providing ways to slow overland flow of runoff to streams.

Maintaining Soil Infiltration Rates

Generally, the way to maintain soil infiltration rates is to keep vegetation healthy. The principal way precipitation overwhelms infiltration capacity is by droplet impact compacting the soil surface. Machine, hoof, or foot traffic across a site can create the same effect. Keeping vegetation growing on a site cushions traffic effects and provides the point of initial impact for rain droplets, reducing soil surface compaction. Accumulations of organic debris such as forest litter serve the same purpose.

Opportunities exist to manage land to maintain vegetation and litter and protect the soil surface. Wildfire prevention, detection, and suppression conserve vegetation and litter and thereby reduce flood damages. Rapid watershed rehabilitation and restoration following wildfires is needed. Fertilizing and seeding with quick-sprouting grasses have been employed successfully to reduce flood damages after fires. Opportunities to employ such techniques will continue. Additional opportunities exist to develop new and better soil protection techniques, such as hydrophilic mulches that protect the soil surface and hold water for vegetation being reestablished. Another technique is production of seedlings in containers. Container-grown seedlings can speed the process of replanting burned-over sites because they can be grown faster than is possible in conventional bare-root seedling nurseries.

Opportunities exist to develop new methods of managing watershed vegetation to maintain soil infiltration rates. Many techniques have already been borrowed from agricultural research and soil conservation practices such as planting trees on the contour instead of straight up and down hills. The opportunity now exists to develop forestry and range applications of more recent agricultural research findings. For example, "conservation tillage" or "no-till" farming is just coming into vogue. These practices no longer employ site preparation techniques common in the 1950 such as deep moldboard plowing or disking and harrowing.

Slowing Overland Runoff to Reduce Flood Peaks

Inevitably, precipitation events occur that overwhelm soil infiltration capacity. These may be severe events such as locally heavy thunderstorms that create flash floods or events of longer duration that saturate soils so thoroughly that infiltration and percolation rates slow down. In urban areas, sanitary engineers have grappled with related stormwater runoff problems for a number of years. Innovations that have become popular in the last decade include altering construction project design to incorporate temporary stormwater detention structures. Detention facilities (e.g. lips around parking lots or roof drains) collect stormwater and retard its entry into sewers, thereby reducing peak flows to sewage treatment plants. In agriculture, strip-cropping is an example. Strips of forage or field crops are alternated with strips of row crops planted on the contour. Runoff from row crops such as corn is impeded in flowing through field crops such as alfalfa. The opportunity exists to develop ways of applying these stormwater management concepts in forestry and rangeland settings.

There are opportunities to manage riparian areas to slow overland runoff. Not only will water flow be slowed, but reduction in velocity will allow sheet or rill erosion sediment to settle out of the water. Many kinds of vegetation can be used to slow overland runoff. Grasses are favored because of their dense root systems, but other kinds of vegetation can be employed. For example, when performing site preparation, strips of brush might be left on the contour to slow runoff until forest or range vegetation is reestablished.

Other land management opportunities to reduce or retard runoff include piling logging debris on the contour and using a bedding harrow or fireplow on the contour to intercept runoff. When laying out roads and trails, they should be angled across slopes following contours instead of going straight up or down slopes. Where that is not possible, water bars and culverts can be designed

to divert and control water. When road or trail locations follow stream bottoms, special care must be taken to avoid damage to riparian areas.

Many flood damages occur when debris is carried downstream with floodwater. Land managers need to take steps to reduce the possibility of timber harvest debris reaching streams. Slash may reach streams, especially where valleys are narrow with steep walls and main haul roads are in a valley. It is often natural to locate landings next to roads and landings are sites where slash tends to accumulate. Managers need to take advantage of slash disposal opportunities further up slope to prevent organic debris from reaching steams. Bridges, livestock fencing, and structures are susceptible to damage from tree tops and limbs carried by floodwater. Many quasi-regulatory programs for controlling nonpoint-source pollution are targeted toward reducing debris in streams for this reason.

Summary

Many activities are standard practices for mitigating off-site effects of resource use. Many activities serve more than one purpose such as reducing nonpoint-source pollution. Opportunities to use these practices will continue to grow as the value of agricultural production and suburban development increases in flood plains. The challenge is to consistently and reliably apply the practices at every opportunity.

SILVICULTURAL NONPOINT-SOURCE POLLUTION ABATEMENT

The smaller areal extent of forest management activities, less intensive site preparation, infrequent harvests, and lower frequency of pesticide and nutrient applications in a given year all result in silviculture generating a much smaller volume of total nonpoint source pollutants than does agriculture. Although silvicultural activities do not appear to cause problems as pervasive as those caused by agriculture or as severe as those caused by mining, they can still lead to localized water quality problems in places where activities are not well managed. Where localized problems occur, an opportunity exists to use nonpoint-source abatement approaches as a remedy. States identifying silvicultural nonpoint-source pollution as a widespread problem affecting 50% or more of their waters are Maine, Vermont, North Carolina, Alaska, Idaho, Oregon, and Washington (Myers et al. 1985).

Range management activities were combined with pasture management in nonpoint-source reports (Myers et al. 1985). Range projects involve the same kinds of activities as forestry. For example, fertilizer and pesticide applications to range provoke many of the same concerns as fertilizer and pesticide applications to forests. Overharvesting of range forage by livestock can lead to runoff and erosion problems similar to forest problems. Range cover type conversions and reseeding operations often involve burning or a combination of burning and chemical or mechanical treatments which expose bare soil to erosion. These actions occur on rangelands at frequencies approximating their use on forests. Consequently, range management activities are viewed much more like silvicultural than agricultural activities. Many of the same opportunities for reducing nonpoint-source pollution exist for range management as for silviculture, as do the vehicles for capturing them.

CURRENT APPROACHES TO IMPLEMENTING ABATEMENT PROCEDURES

Programs to reduce nonpoint pollution from silvicultural activities rely on a voluntary compliance approach in 29 states, a regulatory approach in 5 states (Alaska, California, Idaho, Oregon and Washington) and a quasi-regulatory approach in 6 states (Hawaii, Maine, Massachusetts, New York, New Hampshire, Pennsylvania) (EPA 1984b). Regulatory approaches control activities by using forest practices acts. Quasi-regulatory approaches use laws passed for ancillary purposes such as sediment and erosion control. In western states where the forest industry has substantial land holdings and is very active, regulatory or quasi-regulatory approaches are favored. In states with a plethora of small parcels, voluntary, educational, and sometimes incentive-oriented approaches are aimed at private landowners.

OPPORTUNITIES TO CONTROL SILVICULTURAL NONPOINT-SOURCE POLLUTION

Major nonpoint-source pollutants from silvicultural activities are sediment, chemicals from pesticide applications, and organic debris (EPA 1984b). Principal sources are roads, logging activities, preparation of sites for revegetation, and aerial spraying. Management practices to control these pollutants are well known and well understood. Types of best management practices (BMPs) likely to prove most effective include:

- Better pre-harvest planning;
- Better planning, design, and construction of roads;
- Less soil-disturbing techniques for harvesting, storage, and hauling procedures;
- Closure and revegetation of temporary roads and landings not needed after harvest; and
- Careful application of fertilizers and pesticides.

As in agriculture, adoption of some BMPs will be within the means and self-interest of the landowner and timber operator. For example, proper planning, design, and construction of logging roads intended for long-term use will lower operation and maintenance costs. In other cases, however, adoption of BMPs will not be in the economic self-interest of operators. Needs for specialized equipment may put some BMPs beyond the means of the small landowner or operator. Finally, certain BMPs may be unattractive because they result in reduced income. For example, leaving unharvested timber in riparian

zones costs the landowner money in the short-run but benefits accrue to society.

Nonpoint-source problems are fundamentally land management problems. Thus, adopting BMPs that can also save money presents an opportunity to land managers. Opportunities also exist to develop demonstration areas and to show private landowners and land managers how to secure financial benefits.

Demonstration areas also present opportunities for disseminating information and educating landowners about related issues such as the importance of water quality, the benefits of preserving fish and wildlife habitat, and how to safely conduct harvesting and regeneration operations. Some landowners may need technical or financial assistance to implement abatement procedures during regeneration or intermediate stand treatments. Where abatement procedures cost the landowner money, opportunities exist for the federal government to share the cost through programs such as the Forestry Incentives Program. The landowner also has an opportunity to claim costs of abatement procedures associated with regeneration as eligible costs under the Reforestation Income Tax Credit. EPA (1984b) concluded that agencies with programs that involve the land manager or that affect the relationship between the state and the land manager are key to implementation of nonpoint-source controls for agriculture, silviculture, construction and mining.

REVERSING THE TREND IN LOSS OF WETLANDS

Eighty percent of the wetlands lost between the mid-1950s and mid-1970s was attributed to agricultural conversions. Wetlands are lost to agriculture through two primary activities: direct conversions by draining and/or clearing; and indirect conversions associated with normal agricultural activities. Although direct conversions are responsible for the most lost acreage, indirect conversions may be a major factor in some regions (Office of Technology Assessment 1984). Examples of direct conversion include drainage to expand crop acreage in the prairie-pothole region and clearing and draining bottomland hardwood forests for soybean or rice production. Examples of indirect conversions include the general lowering of the water table resulting from irrigation or altering water management practices so irrigation discharges are no longer available to maintain wetlands.

A number of reasons have been advanced to explain continued conversion of wetlands (Office of Technology Assessment 1984):

1. Elimination of the nuisance and costs of farming around wetlands within cropland;
2. The opportunity to gain relatively productive cropland for the cost of drainage;
3. Changes in farming from a diversified crop-livestock combination to increasing emphasis on row-crop and small-grain production;
4. Rapid increase in tractor horsepower which increases avoidance costs and facilitates drainage of potholes by providing the power to operate drainage equipment (this allows the landowner to drain land at low cost);
5. Continued increase in the use of center pivot irrigation systems that are incompatible with wetlands;
6. Short-term farm income variability which provides investment capital for drainage during periods of high income and increases incentives to expand cropland area;
7. Absence of private returns from maintaining wetlands without government programs; and
8. Low returns from government incentives to preserve wetlands relative to profits from conversion.

In the last two years, two major changes in legislation, recent projections in the Appraisal (USDA 1987), a report by a distinguished public forum, and the new North American Waterfowl Management Plan have combined to change the expectations associated with most of the above reasons. The changed expectations create an opportunity to conserve or restore wetlands thereby altering the trend toward further reductions in wetland acreage.

Legislative changes to conserve wetlands.—The Food Security Act of 1985 contained a "swampbuster" provision that disqualifies farmers who convert wetlands to agricultural use from participating in other USDA farm commodity programs. In addition to the *prima facie* effect of this provision, it also established the principle of "cross-compliance" as a major factor in administering resource management programs. Cross-compliance means that an action is enforced by establishing performance of the action as a criterion for qualifying for some other government benefit. The key is that two actions or programs need not be directly related, but that they affect the same people. In the swampbuster case, continued receipt of crop subsidy payments is contingent upon not converting more wetlands to agriculture. Now that the principle of cross-compliance has been accepted in the resource management area, it presents a host of additional opportunities for influencing private landowners' resource management decisions such as adoption of BMPs for nonpoint-source pollution abatement.

Appraisal projections provide opportunities to conserve wetlands.—The intermediate projections of the Appraisal are founded on several assumptions that run counter to the above reasons for wetlands conversion to agriculture. For example, assumptions about increasing yields due to genetic improvement will mean that equivalent net returns can be obtained by farming fewer acres. Fencerow-to-fencerow planting using all available space will no longer be necessary, so wetlands need not be converted to increase output and income. The net result of the 2030 projections is a 19-million-acre reduction in irrigated acreage. This implies a reduced need for new center pivot irrigation systems, and a 120-million-acre reduction in land farmed.[1] Both reduce the need to bring available wetlands under cultivation. One way to help capture new opportunities to conserve forest and rangeland wetlands is to increase research efforts that will help make technological and policy assumptions in the Appraisal come to fruition.

Public opinion favors wetlands conservation.—A bipartisan panel of state and federal officials, business representatives, and conservationists—the National Wetlands Policy Forum—issued a report in November 1987 containing more than 100 recommendations for protecting wetlands. The group endorsed "no net loss" as an interim goal. This means that no more wetland should be drained or developed than is created or restored. The long-term goal endorsed by the Forum is increasing the wetlands inventory (Peterson 1988).

The Forum concluded that efforts to conserve wetlands were ineffective because of inadequate laws, confusing regulations, and economic incentives that encourage development rather than protection. The panel recommended major legislative changes to give EPA and states more authority over wetlands. It also urged Congress to eliminate federal "inducements" for wetlands destruction such as investments in roads and airports that encourage development on nearby wetlands. The Forum also proposed that tax incentives and programs be created for private landowners who agree to conserve or restore wetlands (Peterson 1988).

The 20-member Forum included three state governors; representatives of the U.S. Army Corps of Engineers, Interior and Agriculture departments; and private groups representing farmers, conservationists, developers, and the oil industry. The panel endorsed the interim and long-term goals and suggested legislative and regulatory changes reflecting a newly emerging public consensus on wetlands conservation and restoration.

A key factor in capturing an opportunity to redirect public policy is timing. When broad-based public support for change emerges—as it did in the early 1970s for doing something about water pollution—public advocates must be prepared to move quickly to take advantage of momentum generated by public support. The National Wetlands Policy Forum report indicates that broad-based public support for wetlands conservation and restoration is building. The time to capture opportunities to change public policies and favor increased wetlands conservation and restoration appears near.

The North American Waterfowl Management Plan.—Waterfowl experts in Canada and the U.S. have developed a plan, endorsed by both governments, that establishes a framework for increasing waterfowl populations back to 1970 levels. Its primary objective is to provide enough habitat to sustain at least 62 million breeding birds and a fall flight of over 100 million birds by the year 2000. The estimated price tag is $1.5 billion (Rude 1988).

Six "Key Priority Habitat Ranges" were identified: Prairie Potholes and Parklands, Lower Mississippi Valley, the Gulf Coast, California's Central Valley, Great Lakes-St. Lawrence Lowlands, and the Atlantic Coast. This plan calls for protection and enhancement of 6 million acres of wetlands ecosystems, which in some cases also include nearby uplands.

The plan will be implemented primarily at the regional and local levels by representatives of various agencies and organizations working with landowners in partnerships coordinated by the U.S. Fish and Wildlife Service and Canadian Wildlife Service. Tools available for protecting habitat include acquisition, easements, incentives, and technical assistance to improve land use practices. Private groups, such as Ducks Unlimited, have a leadership role, especially since the financial burden is to fall primarily on the private sector. This plan is the largest single effort ever undertaken to protect wetlands and waterfowl.

SUMMARY

Clearly, there are opportunities for changing watershed management practices on all ownerships and on all sizes of ownerships. Many principles and methods have already been developed; their consistent application is needed. Some landowners have not applied recommended principles and methods; additional education and technical and financial assistance are needed.

Some opportunities need further research and recent research findings need additional work to develop practical solutions to problems. Additional research and development work is needed. Only through coordinated efforts of all public and private parties can the use of water and related resources reach their full potential.

NOTES

1. Actual reduction in acres farmed from 1982 to 2030 amounts to 160 million acres, 40 million of which are projected to be enrolled in the Conservation Reserve Program established under the Food Security Act of 1985.

CHAPTER 8: OBSTACLES TO IMPROVING THE MANAGEMENT OF WATER AND RELATED FOREST AND RANGELAND RESOURCES

Significant obstacles to improving management of water and related land resources are highlighted in this chapter. Obstacles presented are not in any order of priority. Each contributes to not being able to capture opportunities presented in Chapter 7. Some obstacles identified can be altered by changing resource management policies; others will require new regulations or legislation. Some alternatives to surmounting these obstacles are identified and methods of implementation are suggested.

The obstacles are:

1. Water prices do not reflect true costs to society of supplying water for agricultural use. Devising an acceptable transition from subsidized agricultural production to production where farmers' costs more nearly reflect social costs of inputs such as water will be extremely difficult because the transition threatens major changes in agrarian lifestyles and the agricultural economy.
2. Water institutions are giving high priorities to offstream uses to the detriment of instream uses such as fish and wildlife habitat and recreation.
3. Information that accurately assesses current watershed and stream channel conditions and capabilities on all ownerships is not consolidated. Further, information available is often not displayed to managers in ways useful to evaluate management impacts or plan rehabilitation of watersheds which are in the worst condition.
4. Private landowners lack incentives to implement BMPs to reduce nonpoint-source pollution.
5. Income and property tax laws and regulations encourage wetlands conversion. There are few incentives to encourage private landowners to manage wetlands for wildlife and recreation benefits.
6. Large-scale water yield augmentation entails significant environmental and social risks.

WATER PRICES IN TRANSITION

The projections of water shortages in Chapter 5, implications of shortages discussed in Chapter 6, and opportunities for making changes outlined in Chapter 7 all point to a need for changes in current water resource allocations. A major obstacle to making the changes in an economically efficient manner is that water prices often do not accurately reflect the marginal social benefit of providing or using water. This leads to a misallocation of resources from society's perspective. This needs to be redressed if crop production is to become economically efficient on a national basis and water shortages are to be avoided.

Economic development of the West was water-driven. Between its formation in 1902 and the present, the Bureau of Reclamation has spent $8.7 billion constructing irrigation projects across the West. Today, longstanding ways of distributing water are being challenged. Also, there is plenty of evidence that consumption restrictions and higher prices will occur unless new ways can be found to manage existing supplies (Shapiro et al. 1988). Colby et al. (1988) reviewed state legislation and regulations related to water markets and transfers. In regions where shortages are projected, they concluded that markets have emerged and are functioning reasonably well. The obstacle to resolution of the contentions documented by Shapiro et al. (1988) stems largely from water price imbalances among uses. Correction of the price imbalances threatens to alter the agrarian lifestyle favored by many farmers and other agricultural interests.

During the middle half of this century, and particularly in the 1950s and 1960s, the government strongly encouraged farmers to increase crop production. Public policies were employed to stimulate production and western farmers were offered water from Bureau of Reclamation projects at prices that were substantially subsidized by the federal government. Further, if farmers produced more crops in aggregate than society demanded, the government bought the surplus at very near market prices. According to a recent Interior Department report, 38% of western farmland getting water from federally sponsored irrigation projects is used to grow crops that are eligible for federal subsidies because they are in oversupply (Shapiro et al. 1988). Because of irrigation subsidies, crops needing substantial amounts of water, such as hay and alfalfa for cattle feed, cotton, and rice, are being grown under irrigation in water-short areas when they could be grown in other parts of the U.S. at lower total social cost (when the government irrigation water subsidies are factored out).

Times are changing, and so are government policies. In this era of large federal government deficits, federal water resource managers and congressional decisionmakers are re-examining fiscal priorities to determine if continued subsidization of irrigation projects and surplus crops is socially desirable. For example, the House Appropriations Committee provided no funding for new irrigation projects in the 1989 budget. The Appraisal assumptions include cessation of farm commodity programs for purchasing surplus crops and a reduction of 19 million acres (32%) in irrigated cropland by 2030.

These kinds of actions foretell a major change in the agricultural sector of the U.S. economy; one that will not only affect farmers, but ripple through farm suppliers, manufacturers, distributors, and retailers of farm implements, irrigation hardware, fertilizer, and agricultural chemicals, down to consumers of farm products. All will experience some effects of the adjustment; farmers in regions where water shortages are imminent have already begun to experience changes. Irrigated acreage has dropped 1.9 million acres from its peak.

This is a classic economic case where what is good for a region or locality differs from what is beneficial from the national perspective. If we could ignore local con-

cerns and do what is optimal for society as a whole, water and crop subsidies would be eliminated and the agricultural economy would struggle to adjust to new socially optimal crop production patterns. However, local concerns cannot be ignored.

It is difficult to deal with pending water shortages in an economically efficient manner from a national perspective. The major obstacle is lack of a politically acceptable transition from the current situation where crop production is subsidized to the new situation projected in the Appraisal. Here, subsidies are substantially reduced or gone. Until such a transition is developed, groundwater mining will continue at rates above long-term acceptable levels and instream uses of water will be under-supplied.

INSTREAM USES HAVE LOW PRIORITY

The water budgets of Chapters 5 illustrate that of the four key variables affecting water balance—precipitation rates, instream flow levels, rate of groundwater pumping, and rate of offstream consumption—only the latter three are under the manager's control. The manager takes precipitation that nature provides and chooses levels of two of the latter three variables. Once the levels of two are chosen, the level of the third variable provides the balance.

In many states, water managers chose the rate of groundwater pumping and the rate of offstream consumption and let the instream flow levels provide the balance. The consequence is that instream flow levels are highly variable and may not always meet the flow requirements for optimal, or even good, survival habitat outlined by Tennant (1975). In dry years, groundwater pumping proceeds at the maximum rate and offstream use slackens a bit but instream flows drop considerably. Some streams in the southern Great Plains, New Mexico, and Arizona dry up completely. In wet years, groundwater pumping slackens somewhat and reservoir refilling occurs to prepare for the next dry year. Instream flows rise and balance the equation, but, like the runt in a litter, only after all other uses are satisfied. Consequently, offstream uses create externalities affecting fish and wildlife populations and recreation activities. This priority of operations is also reflected in priorities for water uses. In Arizona, for example, the priority of water use has been established as follows: (1) domestic and municipal supply, (2) irrigation and stock water, (3) mining and power generation, (4) recreation, wildlife, and fisheries; and (5) artificial groundwater recharge (Colby et al. 1988). Offstream uses first, then instream uses, and finally something to recharge overdrawn aquifers.

A CLASH OF PRIORITIES IS THE OBSTACLE

Since the 1979 Assessment, there has been a surge in public interest in fishing and water-based recreation. The effects of cleaning up rivers and streams to make them fishable and swimmable again in response to the Clean Water Act has provoked increased interest in water-

Participation in fishing and water-based recreation has skyrocketed since passage of the Clean Water Act. It will be impossible to resolve future deficits and meet increased demands for these instream uses without changing water rights laws.

based recreation. Fishing participation continues to increase rapidly, according to the 1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation (Fisher 1988). Other water-related recreation activities also have enjoyed increases in participation.[1] Near urban areas and especially in warm climates, summertime water-based recreation is booming. The question is, how will projected increases in demand for instream water-based recreation be served by declining instream flows? The obstacle to meeting increased demands is the low priority given to instream flows compared to offstream water uses.

Whether or not social preferences among water uses have changed needs to be determined. The political process is one way of gauging changes. However, it is often difficult to get a clear reading of social consensus on a particular issue from the political process because elections are rarely decided on a single issue and because elections occur relatively infrequently. Markets are an alternative to elections for gauging social consensus. In markets, people vote with dollars and they vote frequently—each transaction instead of each election is another datum.

The "Nature Conservancy" approach.—Where the prior appropriation doctrine of water rights is used and markets for water rights are functioning, one method of gauging the consensus for increasing instream flows for recreation is to let the market function freely. Let interest groups purchase water rights and dedicate these rights to instream water uses. This approach is a water-based parallel of land purchases the Nature Conservancy has practiced for years.

The Nature Conservancy acquires property, often at fair market prices, and dedicates these holdings to management for recreational and preservation purposes. The Nature Conservancy manages some of the lands purchased, but also creates partnerships with public agencies to manage property purchased to meet Conservancy goals. The Conservancy has often functioned as a third party in purchases where a public agency wants to acquire a private holding. The Conservancy buys rights when a land management agency does not have funding for that purpose. In a subsequent year after receiving appropriations, the agency purchases the property from the Conservancy and dedicates it to recreation and preservation purposes.

Water markets emerging in the West are managing water rights more and more like real property. One way of providing more water for instream uses is to modify water rights laws and regulations to allow water purchases for dedicating the water to instream uses. Modifications should explicitly declare maintenance and improvement of fish and wildlife habitat and water-based recreation to be beneficial water uses. In addition, most state water laws declare that water must be used (offstream) or rights are forfeited. Where water is reserved for instream use, that water is reserved in the name of the state. Protections need to be added to water laws to assure that water purchased by groups will not be subject to re-appropriation by offstream users who want to put it to a "higher" or "more beneficial" use. Also, instream water rights should be allowed to be in the name of a party other than a state.

The "Multiple-Use" approach.—Reservoir operators in the Appalachian Mountains are receiving increasing numbers of requests for water releases to make certain recreation activities possible. The Corps of Engineers has been a leader in timing reservoir releases to meet the needs of recreational water users. For example, special reservoir releases from Francis Walter Dam, built primarily for flood control on the Lehigh River in northeastern Pennsylvania, are made for 12 to 18 hours on weekends to create whitewater rafting opportunities. The schedule of releases is advertised well in advance so outfitters and private raft owners can make recreation plans. On the Savage River in western Maryland, national and international kayaking and canoeing competitions are held with special reservoir releases. Similar reservoir operating schedules were implemented in Tennessee and north Georgia for rafting on the Ocoee and other rivers.

In establishing reservoir operation schedules such as these, environmental assessments should be conducted to evaluate effects of short-term variations in flows. In some areas where fish and other aquatic organisms are suffering from poor survival habitat, flow variations of this sort may not have significant additional adverse effects.

SUMMARY

A reconsideration of water use priorities is inevitable. Crop production is changing in response to market signals and public policies. Per-acre crop production potential is increasing faster than demand—that's the implicit Appraisal assumption behind the projected 120-million-acre decline in acreage farmed between now and 2030. As crop production changes in quantity and geographic distribution, so will consumption of inputs to crop production such as water. As water use in agriculture changes, so will all other uses of water. Fish, wildlife, and recreation should be freed from constraints that relegate them to lower status than offstream water uses. Thus, when water use changes occur, water markets can function freely to attain a social optimum.

WATERSHED CONDITION ASSESSMENTS REQUIRE BETTER INFORMATION

Watershed condition is a concept discussed in general terms for years. However, only recently has the concept been translated into a practical definition usable in land management (Chapters 2 and 7). Three condition classes were identified that link management goals and the land's current condition and capability to meet the goals.

Two major management uses of watershed condition classification serve to evaluate the amount of erosion likely to be created by use and to assign priorities for watershed rehabilitation and restoration project planning. Before land managers can use watershed condi-

tion classifications for these purposes, however, current land condition and capability information must be available. Stream channel types and conditions should also be described. Only then can site impacts from use be evaluated and planning priorities be assigned.

The obstacle to using watershed condition classifications in land management evaluation and planning is that information on current land condition and capability and stream channel types and conditions is not available for all areas.

RESOURCE INVENTORY DATA MUST BE CLEARLY PRESENTED

The U.S. Department of Agriculture conducts several different inventories that provide useful information to resource managers. Some inventories provide information on a regional basis. The Natural Resources Inventory (NRI) is conducted by SCS every five years. It provides a snapshot of land uses and related information focused primarily on crop and forage production. The Forest Service conducts resource inventories of forest and rangeland across the U.S. Inventory cycles range from 10 to 15 years, depending on the region. Mid-cycle updates are based on subsamples. The focus here is on vegetation cover types and production levels. These inventories provide useful information for this Assessment and the Appraisal, but data is too general for use by land managers contemplating specific projects in particular watersheds.

Incomplete data coverage.—The National Cooperative Soil Survey (NCSS), led by SCS, conducts soil surveys that provide watershed managers with much useful information on soil types, textures, and other essential information. Federal agencies, such as the USDA Forest Service, conduct soil surveys and related land resource inventories on public lands by following NCSS standards. Although soil surveys have been conducted since the beginning of the 20th century, complete coverage has not been attained. Because the focus of soil surveys has been on crop and pasture lands, gaps in coverage fall most heavily on private forests and rangeland.

Where land cover types have been changing from crops and pasture to forests such as occurred in the South in the early part of this century, soil survey coverage of forest land is better than in other regions. Nevertheless, a lack of complete coverage of counties where forests or range predominate is a hindrance to implementing and using watershed condition classification.

Unconsolidated data.—Land capabilities and current situations on many sites have been evaluated by field personnel of various federal, state, and local agencies. For example, SCS District Conservationists and county extension agents know current situations and capabilities of the lands and streams in their areas. On each national forest, a Watershed Improvement Needs inventory is periodically conducted. The major problem with the practice of performing capability and situation evaluations on a decentralized basis is that it is difficult to present a consolidated summary of information for the entire watershed. Consequently, land managers have incomplete data for assigning project priorities. Decisionmakers have only partial information for balancing watershed improvement needs against other resource management needs when allocating budgets.

A major reason for this inability to consolidate data on a watershed basis is the patchwork-quilt distribution of land ownership within a watershed. One or two locations creating problems in a watershed that is otherwise in satisfactory shape can adversely affect water quality and constrain use of the total flow coming from a watershed. Differences in land ownership and associated differences in the mission of agencies serving different types of landowners create an obstacle to evaluating impacts, setting priorities, and attaining water quality goals on a watershed-wide basis.

The first step toward surmounting this obstacle is to find ways to consolidate, standardize, and display data already collected for different land ownerships by different agencies at different levels of government. The objective is to lay a foundation of data needed to coordinate solutions to watershed problems and build partnerships among landowners and those agencies offering technical and financial assistance to implement solutions.

Geographic Information Systems (GIS) may help in this process. The key is finding a way to standardize data collected by different entities for related purposes over parts of watersheds and putting this into a single overlay for the entire watershed. Until this becomes possible, it will remain difficult for managers to evaluate cumulative effects and assign priorities. GIS will not make existing information better. But it will make data more usable by providing a mechanism for storing and displaying consolidated data. Having the mechanism provides an impetus to consolidate data already collected by different agencies.

Significant strides have been made in the past two decades in using aerial photography and remote sensing to map overstory vegetation. Advances have also been made in using these techniques to distinguish among some soil characteristics such as moisture because of their influence on light reflectivity. For example, the extent of wetlands along stream channels or reservoirs can be mapped using photography or remote sensing. Preparing maps this way reduces cost and amounts of field labor. Instead of collecting all data needed to prepare maps, maps already prepared based on photography and telemetry need only to be verified. Similarly, some differentiation among forest cover types has been achieved based on leaf reflectivity.

Aerial photography and remote sensing provide complete geographic coverage of the U.S. Geographic resolution is approaching acceptable levels for GIS proposed by state and federal resource management agencies. These methods of data collection are not capable of providing all the details on mid-story and understory vegetation or on soil and stream channel characteristics needed by watershed managers for a condition classification system.

The consequence of not having consolidated data for all landownerships is that decisions on watershed reha-

bilitation and restoration priorities will be made based only on ownerships for which information exists. Because coverage is incomplete, it cannot be determined if expenditures targeted on the areas with known problems will provide the largest possible improvement in overall watershed and water quality.

Soil survey work.—Additional work is needed to gather complete soils and stream channel information on forests and rangeland. For example, about 80% of the soils inventory on national forest is completed. The inventory should be completed without delay. It should emphasize information necessary to make management decisions concerning soil, site, and water productivity and impacts of site use. Additional work is also needed on how to summarize and display the information collected. This should go beyond building GIS overlays so that it can contribute to management decisions.

This work is only getting started. Watershed managers and decision makers need to play a stronger role in this effort. There is a need to articulate the kinds of decisions expected based on watershed condition classifications and data. Then, data analysis and presentation procedures must be developed or updated to meet needs—no small task.

More work is needed to test the validity of information already collected. Validation is likely to be a difficult research task. Validation presupposes that a clear cause-and-effect relationship has been developed between the soil, site, or vegetation characteristics and project- or activity-related impacts, such as erosion or water flow regimes, that watershed managers hope to evaluate. If these relationships have not been developed through research, they should be, as they are a necessary precondition to developing inventory sampling and data validation procedures.

A primary beneficiary of better watershed-level information will be nonpoint-source pollution control and erosion modelling work. Because sediment is the primary nonpoint pollutant from forests and rangeland in terms of volume, watershed condition information related to soil type, texture, and erodibility are key needs. A multiagency task force of U.S. Department of Agriculture experts has begun work on the Water Erosion Prediction Project (WEPP). WEPP's goal is to improve prediction of surface erosion and sediment yield and their on- and off-site impacts. It is hoped that the WEPP model will replace the Universal Soil Loss Equation developed in the 1950s for predicting forest and rangeland erosion and impacts. The WEPP framework includes elements for surface erosion, sedimentation-slope relationships, off-site damage, channel routing and stability, mass failure rates, and watershed condition. Data discussed in this section is needed to project these WEPP elements. WEPP information needs to be integrated with data analysis, consolidation, and display tasks already discussed.

LACK OF INCENTIVES TO USE BMPs

Nonpoint-source pollution has emerged as a major problem in many areas now that major point sources have been cleaned up. Sediment is the major nonpoint-source pollutant from forests and rangeland. Undisturbed, mature forests generate very low annual sediment loads of less than 0.5 tons per acre. Disturbances are caused by most typical management activities, each of which has a different potential for causing nonpoint-source pollution. Road construction, harvesting, fire, and preparing for regeneration are the primary activities causing nonpoint-source pollution.

Average erosion rates for well-managed logging activities may be fairly low, perhaps only an additional ton per acre per year. However, erosion rates of 10 to 15 tons per acre per year are not uncommon for harvesting activities. Intensive mechanical site preparation before tree planting can generate sediment at rates exceeding 100 tons per acre per year (Dissmeyer and Stump 1978). In the past decade, managers have become more aware of adverse effects that some mechanized activities such as root-raking can have on soil productivity and sediment loss. Many of these practices are not as widely used today as a decade ago.

BMPs ARE KNOWN

Research has successfully identified major causes of sediment production. Practical procedures to reduce sediment production and mitigate sediment damages have been developed. WEPP is producing predictive models that will help managers evaluate the likelihood of environmental damage to a specific site from various activities. Thus, silvicultural and range-related BMPs are known and the ability to predict effects is being developed.

Why are some landowners not using BMPs when engaged in soil-disturbing activities? There are three reasons for this. The first is that erosion is an externality and the market provides little or no incentive to use BMPs. The second is that employing BMPs is often not in the economic self-interest of a landowner. The third reason is that knowledge about BMPs has not been effectively transferred to all landowners.

Erosion is an externality.—Erosion as an externality was discussed in Chapter 2. Sediment typically imposes few short-run costs on a landowner; operating savings may even occur if no attention is paid to sediment generation. For example, two and three decades ago, if a skidder could be driven back and forth across a stream without bogging down, it was. By continually crossing the stream, the costs of installing culverts or building a bridge were saved. Fish habitat destroyed or the cost of added water treatment by downstream municipalities did not show up on the landowner's ledger. Thus, the landowner was not paying full costs of his land management decisions.

Libby (1985) noted that there is no incentive for an individual to personally bear the cost of producing benefits for others. Motivated by the Clean Water Act, state governments are now intervening in the market and establishing legislation and regulations to levy civil and criminal penalties for creating nonpoint-source pollu-

tion. Incentives are being created that force those creating the problem to bear fiscal responsibility for sediment production.

Using BMPs costs money.—In spite of laws and regulations, some landowners are not using BMPs. Myers et al. (1985) noted that adoption of only some BMPs is in the self-interest of landowners and equipment operators. For example, using BMPs to construct proper logging roads intended for long-term use can produce savings both in terms of lower road maintenance costs as well as in lower repair rates for vehicles using the road. In most cases, however, using BMPs is not in the economic self-interest of the owner or operator.

There are two ways to alter the situation where using BMPs costs the landowner more than is provided in benefits. The incentive approach uses financial payments to make it more profitable for landowners to use BMPs. Cost-sharing and income tax credits are the two current vehicles available. To encourage more widespread use of BMPs, funding levels for incentives should be increased. Not only should more landowners be able to participate, but the economic benefit per landowner should also be increased.

To use the enforcement approach, costs of not employing BMPs should be increased. There are two elements to this approach—a penalty for getting caught not using BMPs and the likelihood of prosecution. Both elements enter the landowner's decision whether to pay the added costs of using BMPs. Increasing the aggressiveness of enforcement increases the likelihood of getting caught and helps ensure that a financial penalty is likely. Increasing financial penalties is one alternative. Increased enforcement usually costs the government money and goodwill, whereas increasing fines for lack of compliance results in financial returns to government.

Now that cross-compliance has been adopted as a mechanism for levying penalties in the agriculture land use sector, it may also prove an effective means of securing use of BMPs in silviculture and range management areas. Eligibility for forestry incentive payments should be contingent upon using BMPs.

Whether to use the incentives or enforcement or a combination of the two is a decision involving aspects of public administration, public policy, and politics. For example, regulatory programs are popular in the West where numbers of forest landowners are relatively few and the size of holdings makes BMPs more affordable. Incentive programs are more popular in the South with a large number of forest landowners and small average size of individual holdings. There BMP costs are more difficult for an individual to absorb, plus costs of enforcing regulations among a large number of small landowners is administratively and politically difficult.

Landowners lack knowledge.—Forest and range landowners tend to perform soil-disturbing activities at infrequent intervals. Many forest landowners harvest timber only every 10 to 15 years; for some, once in a lifetime. In addition, many landowners undertake timber harvesting or range rehabilitation without obtaining assistance from either private consultants or public servants. Consequently, the uninformed landowner does not take necessary steps to avoid nonpoint-source pollution in project planning and project supervision.

Sorenson (1985) reported that information programs for nonpoint-source pollution abatement were in a pioneering stage and that much remained to be learned. His experience in Wisconsin with one of the earliest programs provided the following insights:

- Identifying specific objectives of the information program is a key element. While the ultimate objective is reducing nonpoint-source pollution, identifying more detailed objectives for information program elements is essential.
- There is usually more than one audience and each has different needs. The community in general is usually one audience separate and distinct from the specific landowner creating pollution problems.
- It usually takes more funding and time than planned to develop an effective program whose success can be evaluated in terms of on-the-ground results.
- Any information and education program will be a cooperative effort among federal, state, and local agencies. Preparing written agreements outlining the role of each cooperator, updated every few years, will assure that gaps and overlaps in outreach efforts are minimized.
- A variety of activities to reach everyone in target audiences should be planned.
- Evaluation is an important, albeit difficult, part of the information and education program. Finding out what works and what does not is the only way to make programs more effective. Deciding on the measures of success is often a most difficult aspect of conducting a program evaluation. Consultants can be of assistance in this phase.

Because agricultural activities are a much larger component of the nonpoint-source pollution problem than silvicultural activities, information and education programs targeted at agricultural audiences are being developed in some states. Agencies concerned about silvicultural nonpoint-source pollution may be able to cooperate with those having ongoing agricultural information and education programs. Alternatively, agencies concerned with silvicultural nonpoint-source pollution will be able to learn from experiences of those serving the agricultural community if a separate silvicultural program is warranted.

SUMMARY

Wilson (1985) discussed provisions of the Oregon Forest Practices Law and how it is implemented to reduce silvicultural nonpoint-source pollution. His description demonstrates the importance of information and education efforts and how they can be combined with rules and enforcement procedures into an integrated program to maintain forest productivity. State agencies are the logical institutional units to coordinate programs to implement BMPs. Federal agencies need to provide financial and technical assistance to help states design programs. Federal agencies also should be ready

to help deliver assistance to landowners during program implementation. A coordinated institutional approach gives private landowners incentives needed to use BMPs and help state-run programs achieve consistency with national nonpoint-source pollution abatement goals.

CURRENT LAWS ENCOURAGE WETLANDS CONVERSION

There are two major categories of tax incentives to convert wetlands to "higher and better" uses such as crop production and urban developments. These are income tax laws and regulations and property tax laws and regulations. The income tax code operates primarily at the federal level. State income tax laws often contain the same provisions encouraging wetlands conversion as does the federal code. Property tax laws are commonly enacted at the state level and enforced at the local level.

INCOME TAX INCENTIVES

The income tax code provides deductions for all types of general development activities and is the most significant federal incentive for farmers to clear and drain wetlands. The result is that a significant portion of wetlands conversion costs are shifted to the taxpayer. The dollar value of tax incentives is higher at higher income levels. The Office of Technology Assessment (1984) listed four major incentives to wetlands conversion. 1986 changes in the income tax code altered two of them. The four incentives mentioned are:

1. First-year tax deductions of up to 25% of gross farm income are allowed for draining expenses. Expenses in excess of this limit may be deducted in subsequent years.
2. Tax deductions are allowed for depreciation on all capital investments necessary for draining or clearing activities.
3. Tax deductions are allowed for a portion of interest payments related to draining and clearing. The 1986 changes in the income tax code provide for gradual phasing out of this deduction, unless interest is on a home equity loan.
4. Investment tax credits equal to 10% of drainage tile installation costs are allowed. The 1986 changes in the income tax code eliminated this tax credit.

PROPERTY TAX INCENTIVES

Property taxation encourages wetlands conversion through assessed valuation of a parcel. Wetlands are not commonly used for income-producing purposes, hence assessed value is low. When wetlands are converted to a use producing income, assessed value is usually increased. When the assessed valuation increment is big enough that the tax increase makes the income-production process no longer financially attractive, landowners are put in the position of either discontinuing the activity or selling the land.

Property assessment guidelines are commonly quite broad and general. In the hierarchy of uses, land used for business purposes is often assessed a higher value than land used for private purposes. Assessment guidelines also make it easier to raise assessed value than to lower it.

Here is a generic example of how property tax administration has often encouraged wetlands conversion. A farmer has wetlands on his property. Assessment guidelines do not provide for unproductive areas in fence rows and similar land to be subtracted from producing acres when the assessment is conducted. The assessor rules that wetlands shall be treated as fence rows. So the farmer is required to pay several hundred dollars in taxes each year on land that produces no income. In the occasional bountiful year, the farmer takes advantage of income tax rules and spends some added income on draining a portion of the wetlands. Over time, the entire area is drained and converted to production of income. Repeated thousands of times annually across the U.S., the net result is losing several hundred thousand acres of wetlands per year.

REDUCING THE INCENTIVES

There are both direct and indirect approaches to reducing incentives to convert wetlands. Direct approaches involve changing tax codes and property assessment guidelines. Indirect approaches are like cross-compliance; let the tax incentive remain but add a penalty that reduces usefulness of the incentive or increase payments providing a counterincentive to the tax incentive.

Direct Approaches

Change the income tax code.—The direct approach of changing the income tax code to disqualify wetlands conversions has not been used. Legislation declaring that the cost of converting wetlands is ineligible for deduction or amortization is the kind of precise remedy that has a reasonable chance of passage. The key is whether a political consensus could be mustered to show that preserving wetlands is socially desirable. Alternatively, a provision establishing a new tax credit for retaining and restoring wetlands, much like the forestation or reforestation tax credit, would also work. The approach would be to compensate landowners for the additional tax burden borne by keeping wetlands in place. The political efficacy of this approach is judged to be much less than the former proposal.

The 1986 changes to the federal income tax code consolidated income brackets into three broad brackets and lowered marginal tax rates for higher incomes. The net result is that lower marginal tax rates reduce benefits of converting wetlands to other uses because deductions are no longer worth as much to the taxpayer. Another provision in the 1986 changes reduced the deductibility of consumer loan interest unless the loan is tied to prop-

erty equity. This may have some effect on a farmer's willingness to borrow money to drain wetlands. The investment tax credit formerly available for installation of drainage tiles was abolished by changes in the law.

Change the property tax code.—The direct approach to changing property taxation regulations hinges on modifying assessment valuation guidelines. Changing laws and guidelines state-by-state takes time. It took several decades for the current use valuation principle to become widely applied to forestry. This principle is that property shall be assessed as forest land if uses such as forestry are deemed desirable. To qualify for the lower assessed value as forest land, trees must be kept on the land regardless of other potential values such as cropland or industrial development.

The first step in securing use valuation for wetlands is to attain consensus that such lands are socially desirable and get that preference written into law. The second step is to modify assessment valuation guidelines so that surveys recognize wetlands and assess their value accordingly.

Indirect Approaches

The indirect approach has been the preferred approach to date. The swampbuster provision of the Food Security Act of 1985 is the latest provision. It reduces conversion by denying eligibility for federal farm benefits to those growing agricultural crops on wetlands whose conversion began after December 23, 1985. It is important to note that this provision neither protects wetlands nor prohibits drainage or modification. It is too early to tell what effect this provision is having on the wetlands conversion rate. Recent market conditions for agricultural commodities making conversion unprofitable and the swampbuster provision may slow conversion (Feierabend and Zelazny 1987). If converted wetlands are not used to grow crops subsidized by the government, no penalty ensues. The effectiveness of swampbuster will not be tested until crop prices recover and it once again becomes profitable to convert wetlands to boost crop production.

The 1977 amendments to the Clean Water Act provided language giving the Corps of Engineers rulemaking discretion to include wetlands within the Section 404 program.[2] The Section 404 program gave the Corps responsibility for regulating discharge or disposal of dredged or fill material. The Corps views its primary function in carrying out the law as protecting water quality. Although wetlands values are considered in reviewing project permits, the Corps does not believe that Section 404 was designed specifically to protect wetlands (Office of Technology Assessment 1984).

The 404 program provides a major avenue for federal involvement in regulating activities that use wetlands. However, it was not designed to stop wetlands conversion. The 404 program only regulates the discharge of dredged or fill material onto wetlands. Projects involving drainage, clearing, or flooding of wetlands are not explicitly covered in the legislation, hence are not regulated directly by the Corps. Thus, instead of preventing wetlands conversion, the thrust of the program is to prevent water quality degradation from activities affecting wetlands. The consequence is that some wetlands conversions have been avoided, but the extent is difficult to estimate. Office of Technology Assessment (1984) concluded that without more direct government involvement, conversion of most inland wetlands is likely to continue unabated. It appears that the swampbuster provision of the Food Security Act of 1985 was a congressional response to the above conclusion.

The 404 program provided some disincentive to convert wetlands. In 1981, acreage affected by requested permits totalled about 100,000 acres. As ultimately approved by the Corps, acreage affected totalled about 50,000 (Office of Technology Assessment 1984). Of approximately 11,000 permits received annually, about 3% are denied, about 14% are withdrawn by applicants, about 33% are modified significantly, and the remainder are approved without significant modifications.

Other federal agencies, such as the FWS can participate in the permit review process, but EPA has veto power over permit approvals. The National Marine Fisheries Service of the Department of Commerce estimated that the 404 program, in combination with state programs, reduced coastal wetlands conversion by 75 to 80% in 1981. EPA has used its veto power less than a dozen times between 1977 and 1984 (Feierabend and Zelazny 1987).

There are four principal nonregulatory programs that help protect wetlands. Most of these involve land acquisition and are designed to protect wetlands from drainage and destruction through purchase or lease. The 1929 Migratory Bird Conservation Act authorized federal acquisition of land for migratory waterfowl refuges. The 1934 Duck Stamp Act established funding for the Migratory Bird Conservation Act through sales of federal migratory bird hunting stamps called "duck stamps" to all hunters aged 16 and older. Funds collected are used to acquire habitat for migratory waterfowl, including wetlands and related uplands areas used for nesting and cover. Since enacted, the duck stamp program has generated nearly $313 million, used to acquire more than 2.3 million acres (Feierabend and Zelazny 1987).

The Wetlands Loan Act of 1961 was intended to accelerate federal acquisition of migratory waterfowl habitat. The law, extended through 1988, authorized additional federal appropriations as a loan against future revenues from duck stamp sales. As of 1985, more than $190 million had been appropriated for acquiring additional habitat.

The Land and Water Conservation Fund was established in 1964 and also provides money for land acquisition financed by receipts from offshore oil and gas revenues. Legislation establishing the fund authorized Congress to appropriate up to $900 million annually. Annual appropriations have always been a fraction of the authorized level. As amended by the Emergency Wetlands Resources Act of 1986, the fund can also be used to acquire wetlands. The act also requires states to include acquisition of wetlands as part of their statewide

comprehensive outdoor recreation plans. The 1986 act also increased the level of funding going into the Migratory Bird Conservation Account.

The Water Bank Program, administered by the Agricultural Stabilization and Conservation Service, authorized $10 million per year for 10-year leases of waterfowl habitat from private landowners. Few funds have been appropriated for this program in recent years. As of April 1987, the program had funded 4,615 leases, protecting 153,073 acres of wetlands and 332,861 acres of adjacent uplands (Feierabend and Zelazny 1987).

SUMMARY

The slow grinding of the political process is a factor in implementing tax code changes or expanding indirect approaches for halting wetlands conversion. The process will not accelerate unless a political consensus emerges indicating that additional federal help is needed to conserve wetlands. It may be easier to secure the needed consensus at the state level to obtain changes in state legislation.

Nonregulatory vehicles available have proven effective in conserving wetlands. With additional appropriations, more could be done without significantly expanding the bureaucracy needed to implement programs.

IMPACTS OF LARGE-SCALE WATER YIELD AUGMENTATION

The three water yield augmentation measures identified as management opportunities in Chapter 7 are vegetation management, snow trapping structures, and weather modification primarily through cloud seeding. The efficacy of each of these measures for increasing water yields has been demonstrated in pilot tests. They have never been implemented on the scale necessary to have significant impact. Environmental and social impacts of large-scale use of these measures constitute the major obstacle to employing them in a coordinated way on a regional basis.

The cumulative nature of impacts generated to make a significant contribution to regional water yields makes them important. Employing measures in a single watershed is insufficient. Most watersheds in the Upper Colorado region must be managed for water yield if projected water shortages in the Upper and Lower Colorado regions are to be alleviated. Consequently, the implicit tradeoff being considered is to mitigate major impacts in the social structure of agricultural communities along the middle and lower portions of the Colorado River basin by making major alterations to the environmental and social character of forest and rangeland management in the headwaters of Colorado River tributaries. This section looks at impacts likely to occur in the headwaters to provide a better foundation for evaluating the role of water yield augmentation in alleviating projected shortages.

ENVIRONMENTAL IMPACTS

Implementing the three augmentation measures over wide areas will create significant environmental impacts. The focus here is on the two major impacts—a significant increase in timber cutting[3] and stream channel integrity.

Timber Cutting

Vegetation management relies upon a reduction in evapotranspiration as a major vehicle to obtain water yield increases. Cutting timber in correct patterns can improve the ability of an area to trap snow and delay snowmelt into early summer. However, this does little to increase total regional flows.

Some level of clear cutting will be necessary to provide patchy cover necessary to trap blowing snow. Thinning will also be needed to regulate the amount of shade and timing of snowmelt. At altitudes where cutting is needed, soils tend to be more fragile and unstable than at lower elevations. Consequently, any cutting that increases the amount of water in the soil increases the hazard of landslides. The likelihood of increased numbers of landslides must be considered when evaluating feasibility of a major regional commitment to water yield augmentation and during project-level planning such as for road and timber-cutting layouts. If soils were consistently stable or consistently unstable, it would be easy to deal with whether more landslides will occur. But the fact is that soil stability in high-elevation watersheds tends to be quite variable. Thus, planning and decision-making are all the more difficult.

After timber cutting, ecological succession begins. Water yields usually remain high until trees are reestablished and their crowns close. Delaying crown closure will pay benefits by keeping water yields elevated.

Fire and herbicides are the most common practices used to retard ecological succession. For example, chaparral needs to be burned every 12 to 15 years to keep water yields high. Although fire is relatively inexpensive, the difficulty of using it on slopes is retaining enough vegetation on the site to keep the soil anchored. This usually requires cool, low-intensity burn. Such fires can easily overrun the prescription boundaries.

Herbicides and application rates can be chosen to selectively kill some plants but not others. For example, products are available that will kill broadleaved plants but only stunt grasses. These herbicides are quite popular in right-of-way maintenance beneath utility lines and along highways. A single herbicide treatment each year has reduced the mowing frequency in highway medians by more than half, yet the grass remains effective in preventing erosion. Thus, using herbicides can reduce the likelihood of sediments polluting water supplies.

A benefit from using vegetation management to augment water yields is the creation of a more diverse vegetation structure. Clearings will be interspersed with areas thinned and where no cutting has occurred large amounts of edge will be created. Thus, the area will pro-

Although researchers have demonstrated the feasibility of trapping increased amounts of snow and delaying melting in experimental watersheds, the environmental and social impacts from widespread application of these techniques present an obstacle to using them.

vide habitat for a wider variety of wildlife. Adequate cover for concealment and protection from heat and cold will also remain. Larger numbers and a wider variety of wildlife are expected from a more diverse vegetation structure.

The objective of the cutting patterns is to alter the wind flow so that snow falling in cutover areas is blown into and trapped by thinned stands. The clearcut patches will create changes in wind patterns up to several hundred feet above the ground. Currents will be changed and eddies will form. The consequence will be increased hazard of windthrow damage. Trees along the edge between cut and thinned areas on the upwind side will be most susceptible to swirling gusts. Early season snowfalls before the ground is frozen or late spring storms where snow is wet and heavy create the greatest risk of windthrow.

Finally, vegetation management to augment water yields is expensive, especially if the timber cut cannot be sold. Many watersheds along the Colorado River are public land. Given recent Forest Service budget levels, it is not possible to fund vegetation management on the scale described. New partnerships must be created whereby beneficiaries of additional water would help pay to create and maintain flows from national forests.

Stream Channels

Stream channels have evolved due to historical patterns of precipitation and runoff. When major increases in precipitation and runoff occur, higher flows will create environmental impacts. If snowmelt timing is not extended, flood peaks will rise as will water velocity. Higher peak flows will increase flood damages to residents along valley bottoms. Higher flow rates mean that the water has more energy to carry sediment. Increased bottom scour and bank erosion is the result and leads to increased sediment damages downstream.

The purpose of timber cutting is to extend snowmelt duration so flows are higher and extend longer into the summer. The major impact on stream channel integrity will come if winter and early spring weather varies significantly from its long-term average. If wintertime precipitation is abnormally heavy and if the spring thaw is abnormally rapid, then flows will rise rapidly to a peak well above the norm and water velocities will be high. Even the best timber cutting patterns cannot overcome abnormally warm air temperatures. Weather modification plans must take into account stream channel capacities in the event of a sudden warmup. Weather modification should not add more snow to a basin than stream channels can handle.

Despite research, weather modification remains an inexact process. Seeding has been used in recent years to augment snowfall for skiing. But difficulty in controlling where the snow falls has reduced the acceptability of the technique. Snow often continues to fall well past the target area. For purposes of water yield augmentation, targeting is less of a problem as all melt water goes down the same major stream.[4]

Other Environmental Impacts

Research demonstrates that snow trapping structures can be used above timberline. Alpine and tundra ecosystems are much more fragile than ecosystems below timberline. The impact on vegetation from constructing fencing 15 to 20 feet tall can be severe. Fencing must be anchored solidly to withstand severe winds and constructed of materials that will withstand the elements. Considerable maintenance activity may be required that further impacts the surrounding vegetation. When all factors are considered, fencing will probably not become as popular for solving regional water shortages as vegetation management and weather modification. However, fencing will continue to play a prominent role locally in keeping snow off highways, in range management, and for filling isolated depressions for stock and wildlife watering.

Sites undergoing vegetation management to increase water yield need more attention than conventional timber management. Crews will be working on sites every few years. Although such schedules are acceptable in the South for managing southern pine, it is not known if a more intensive management schedule including activities such as burning or herbicide applications every several years will be acceptable in the Rocky Mountains.

SOCIAL IMPACTS

Vegetation management, weather modification, and snow fencing create social and political impacts. Certain impacts are tangible in the sense that they can be mitigated or compensated with dollars from regions that use the added water. Other impacts occur, however, where neither mitigation nor compensation may be feasible.

Large-scale vegetation management will cause visual impacts. Unless cutting pattern design is done with skill and sensitivity, mid- and long-distance mountain views will be adversely affected. Irregular shapes that blend with terrain features are least objectionable. Computer programs exist that enable landscape architects to design cutting patterns and model how views will appear after cutting. Whether views will be socially acceptable is unknown. Structures used above timberline may create additional visual impacts.

Weather modification creates additional snow in both rural and developed areas alike. Public reaction to current weather modification practices is mixed. Concerns were expressed about the ability of roof structures of residential dwellings to carry additional snow loads. More snow requires greater local government expenditures to keep roads cleared. Economic costs such as these need to be considered when partnerships are formed to provide interbasin transfers of water. Social impacts include living with more snow in winter and for a longer time period.

Additional water provided from public lands is subject to appropriation. Forest Service policy is to provide water for other political entities to distribute. Competition among political jurisdictions and interest groups to appropriate increased flows of water will be keen. Conflicts among competing uses are likely to emerge. Additional reservoirs will be needed to capture additional water from increased yield. Reservoir construction will generate additional environmental, social, and economic impacts.

One unanswered question is who will pay the costs of vegetation management, weather modification, and associated water developments? In early decades of this century, the federal government would have played a major role each step of the way. Recently, federal participation in water resource developments has declined. Partnerships between local, state, and federal governments are now needed, with local and state interests sharing a much bigger portion of extra costs. The partnerships are yet to be formed. The social and political compacts needed to reach a consensus on how to deal with projected shortages do not exist. Whether the linkages can be forged, at what cost, and who will pay remain to be seen.

SUMMARY

This chapter has focused upon the six obstacles having the most severe and direct consequences on forests and rangelands and associated wetlands. Obstacles to managing water resources and related lands other than forests and range were not explored here, although many exist. Removing some of the obstacles discussed here, such as making water markets freer or giving instream uses higher priority, will undoubtedly have effects on other uses and obstacles.

The goal of this chapter and the preceding one was to stimulate thought about how to manage water and related lands. To realize opportunities and overcome obstacles will require changes in recent trends of water and land resource allocations and in institutions that manage the resources. Whether we as a nation choose to continue recent trends and endure the likely implications outlined in Chapter 6, or pursue a different future, perhaps realizing some of the opportunities and removing some of the obstacles presented in the last two chapters, requires conscious decisions on the part of society and land managers. One vehicle to involve society in considering these decisions is to outline potential changes in government programs for managing water and related land resources. Then, through discussion of proposed program changes, managers and members of society can interact and begin to build a consensus about management directions.

The 1990 RPA Program will discuss potential strategies for managing water and related land resources on national forests, for assisting states in watershed management, and for conducting research in these areas. To build a linkage to the program, the final chapter discusses the implications of the findings in this water assessment for current and future Forest Service programs.

NOTES

1. See the Flather and Hoekstra (1989) and Cordell (1989), companion technical documents supporting the 1989 RPA Assessment for additional information in increases in fishing and water-related recreation participation rates.

2. A 1975 decision by the U.S. District Court for the District of Columbia, in *Natural Resources Defense Council versus Calloway* broadened the scope of the original 404 program from the Corps' traditional definition of navigable waters (emanating from the 1899 Rivers and Harbors Act) to "all waters of the United States." The issue of the Corps' jurisdiction was hotly debated, but left unchanged in a close vote, when the 1977 amendments to the Clean Water Act were passed.

3. Timber cutting is used here instead of timber harvest, because harvest implies that the trees cut are a merchantable product, when in fact, they may have little or no market value. Merchantability is affected by may things, including tree diameter, species, and the location of the stand in relation to the nearest mill. Increasing the water yield from the site, not obtaining returns from harvesting timber, is the primary land management objective.

4. In Colorado, much of the water used to supply residents east of the Front Range, who live in the Missouri and Arkansas-White-Red regions, comes across the Continental Divide from the Upper Colorado region. These trans-region diversions are ignored in the referenced sentence.

CHAPTER 9: IMPLICATIONS FOR WATER AND RELATED FOREST AND RANGE MANAGEMENT PROGRAMS

The economic, environmental, and social implications in Chapter 6, the opportunities outlined in Chapter 7, and the obstacles discussed in Chapter 8 suggest ways that water and land management programs can alter the future situation projected in Chapters 3, 4, and 5. Many changes have implications for programs of other federal agencies, state agencies, and local organizations. Although some implications will be mentioned in this chapter, the main focus is on implications for Forest Service programs.

Forest Service program implications of the water assessment findings are presented as answers to six questions. These questions provide a structured way of exploring the impact of assessment findings on how the Forest Service manages national forests, provides assistance to states and private landowners, and conducts research. Similar questions are being asked in the other assessment technical reports as a way of strengthening the link between assessment findings and the 1990 RPA Program.

QUESTION 1: WHAT SHOULD THE FEDERAL GOVERNMENT DO TO EASE POTENTIAL SHORTAGES OF WATER AND OTHER WATERSHED RESOURCES?

Potential shortages arise because of a projected gap between future supplies and future demands. If the government does not intervene in the market, the economy will function and prices rise until demand and supply are equal. Rising prices may reduce demand and may provide incentives to boost supplies.

In some cases, allowing prices to rise high enough to equilibrate demand and supply results in price increases judged socially inequitable. Then, government could intervene in the market to curb demand by implementing rationing, or increase supplies by sharing costs of forest regeneration. In addition, government actions may be used to redistribute impacts. Rationing allocates the resource without regard to a user's ability to pay.

THE FEDERAL ROLE

All three levels of government—federal, state, and local—have borne responsibilities for easing water shortages. The traditional federal government response to shortages has been to increase supplies, not to restrict demand. The federal government has intervened to help develop water resources using dams and conveyance structures and has played a role in the expansion of irrigation through decisions about water prices from federal projects.

The Forest Service has been involved in water development projects by providing permits for locating dams and diversion and conveyance structures on national forests. When measures affecting demand are needed, states have played the lead role. Controlling water use and water rights are areas that have historically been state responsibilities. Demand management has traditionally focused on managing the queue of users to assure that everyone gets a fair share.

Arriving at the socially preferred mix of demand and supply management presents an institutional challenge because determining the mix requires state and federal agencies to achieve a joint consensus on their respective roles. State agencies have traditionally undertaken demand management actions while federal agencies have responsibilities for supply management. Further, each federal agency involved in supply management typically has a narrow functional mandate. For example, the Forest Service lacks dam-building authority. The institutional challenge is not only to arrive at a socially-preferred division of responsibilities between the state and federal levels of government but also to decide the extent to which specific federal agencies should be involved. Similar institutional challenges have been met in the past by chartering regional commissions. Examples are the Appalachian Regional Commission and the Delaware River Basin Commission. This approach to institutional coordination was popular in the 1960s and early 1970s. Following the demise of the Water Resources Council in 1982, no group at the federal level has provided coordination among federal agencies with roles in planning and development of water and related land resources.

Projected water shortages in the West and limited capability to combat shortages by building more storage and conveyance structures suggests that a new examination be made of options to manage water and related land resources. One approach to obtain the institutional coordination needed would be for Congress to charter additional regional river basin commissions and reinvigorate those that currently exist west of the 100th Meridian. Commissions could be charged with responsibilities to develop and oversee implementation of regional plans to minimize shortages and resulting adverse effects. Another approach would be for Congress to authorize new "Level A" studies of river basins with projected shortages and use this planning process to explore public preferences for dealing with projected shortages. Whatever approach is taken to decide on the preferred mix of demand and supply management practices, the specific missions and roles of various government agencies must be taken into account.

Vegetation management, weather modification, and construction of snow fencing can all help augment water yield from public forests and rangeland. These practices have proven feasible in studies on experimental watersheds and have been used on a limited scale on national forests in Colorado and California to support ski developments. Expanding the use of these measures to the scale needed to increase supplies substantially and ease water

shortages may create significant environmental and social impacts due to the cumulative effects of using measures on a multi-state basis. In many cases, implementing these measures on the scale needed may be judged too costly.

Major water shortages are projected for the Lower Colorado water resource region. Lesser shortages are predicted for the Upper Colorado, California, Great Basin, and Rio Grande water resource regions. If recent water use trends continue, the Forest Service needs to consider the following questions:

— To what extent should the Forest Service adopt a policy of implementing vegetation management, weather modification, and/or snow fencing construction to help alleviate shortages?

— What contribution should the Forest Service make toward easing water shortages using these measures compared to other supply and demand management measures? What does that imply for the application intensity of such measures and for the scope of geographic coverage?

— How quickly can or should the Forest Service proceed with implementation?

Concurrently with Forest Service consideration of these questions, other federal agencies also need to examine their role in easing projected water shortages.

THE ROLE OF OTHER GOVERNMENT AGENCIES

The major non-price tool available for easing future water shortages is water conservation. Conservation has no widely-accepted definition. In this section, conservation means "use less water". In other reports, water conservation is defined as using the same amount of water more efficiently such as growing more crops with the same volume of water. If crop shortages were the problem, then defining water conservation as improving water use efficiency would help ease the shortage. However, *water* shortages are the main concern. People in the five regions where shortages are projected must conserve more water than the current trend in water use indicates.

The question is what can other government agencies do to help residents conserve water? A second question is whether the federal government has regulatory power to implement water conservation. States have historically had the legal responsibility to regulate water use. In recent years, however, there has been considerable expansion of federal regulatory power into what have traditionally been the states' bailiwick. Most of this intrusion has been justified, constitutionally speaking, through an expansion of authority under the commerce clause.

Few parallels exist at the federal level where conservation practices have been successfully employed. The oil crisis of the early 1970s is the most recent example of major federal initiatives to promote conservation. A variety of tools were used including setting energy efficiency standards for automobile and appliance manufacturers, giving income tax credits for energy-saving home improvements, and increasing funding for mass transit and car-pooling. Although gasoline rationing coupons were printed, rationing was never imposed. It is difficult to imagine how federally-mandated conservation measures similar to those used during the oil crisis would be imposed for water, especially because projected water shortages are not nationwide.

State and local governments, on the other hand, have often taken the lead in promoting conservation on a regional and local basis. Taxes have often been used to increase prices and promote conservation. Non-price methods have also been used. During the oil shortage, gasoline station hours were regulated and 10 gallons was established as the maximum purchase in many areas. In some localities, vehicle license plate numbers were used to implement rationing—if the last digit on the plate was odd, gasoline could only be purchased on odd-numbered days of the month. Similar regulations have been used during temporary water shortages due to droughts. For example, car washes were closed or hours of operation restricted. Citizens with odd-numbered addresses could water lawns only on odd-numbered days. Similar regulations exist in many areas. To implement them, a designated official usually issues a formal declaration that a water emergency exists. Then, regulations go into effect for an indefinite period until the emergency passes.

In contrast to measures designed to deal with droughts on a temporary or seasonal basis, dealing with projected water shortages will require more permanent measures. The measures cited above deal with the symptom of the problem, not the root cause.

THE REAL PROBLEM IS WATER PRICES

Water conservation measures employed so far deal with physical shortages. However, physical shortages are only a symptom of the real problem in the five water resource regions. The major problem creating water shortages is that water used for irrigation is under-valued in the marketplace. It is available at a lower, subsidized price than what it is really worth.

Federal irrigation water development projects were originally designed to sell water at a price covering project costs. But federal government policy has kept prices low, so receipts for water sold are covering only a small portion of project costs. It is a well-known economic fact that items available free or below cost will get greater use than if fair market prices were charged. Water priced below supply costs is the major reason why irrigation comprises 80% of water consumption and why shortages are projected in these five regions.

Institutional barriers have also been erected that prevent a freer market for water from emerging; or where one has emerged, constraints have been imposed that keep the market from functioning efficiently. The barriers and constraints typically hinder the sale of water and water rights to non-agricultural users who are willing to pay fair market price. For example, in some western states water rights cannot be separated from the real estate where they are used for irrigation. Thus,

municipalities that need water to meet the needs of expanding populations and diversifying economies are forced to buy farm real estate to obtain the rights to the water needed.

RECENT GAINS IN PRODUCTIVITY DECREASE RELIANCE ON IRRIGATION

A century ago, federal and state governments embarked on a path of using agriculture to motivate development of the West. The burgeoning population of the U.S. needed agricultural products, railroads were available to deliver crops to distant eastern markets, and irrigation was the technology available in the early 1900s to improve crop productivity. A stimulus to spread development quickly over a wide area was needed. Water development projects provided it. Today, irrigation is used on over 60 million acres but its use appears to have peaked. Nearly 2 million acres have been withdrawn from irrigation since 1980. In parts of the southern Great Plains and Rocky Mountains, it has become too costly to pump groundwater for irrigation. Net returns from dry-land farming equal, and often exceed, net returns from irrigated production in those areas.

Future gains in crop productivity will come more from advances in genetics and biotechnology than from increasing irrigation. New crop varieties have been developed for dry-land farming in semi-arid areas and for saline soils. The Appraisal projects continued increases in agricultural productivity from genetics and biotechnology to 2030. New ways of boosting productivity can be combined with irrigation to meet society's crop needs on fewer acres. New technologies can also be used as substitutes for irrigation. Gains from new methods are the underlying reason why the Appraisal projection of agricultural acreage required to meet society's needs in 2030 is 160 million acres less than today. Irrigated acreage projected is 19 million acres, or one-third, less than today.

Farmers can keep yields and farm income steady using new methods; however, changes will occur in farming and irrigation practices. Changes will affect both farmers and the farm economy because of decreased farm capital invested in irrigation equipment and field leveling, a reduction in sales of products associated with irrigation, and a potential change in asset value of irrigation rights. In theory, farmers should not allow capital already invested to stand in the way of changing to more efficient operations. However, this is not easy. More importantly, many state water rights laws contain provisions that water must be used or rights will be lost. Also, water rights cannot be sold without selling the land formerly irrigated. Such provisions make a decision to abandon irrigation very difficult because either farm size must be reduced or a valuable asset—the water right—will be lost without compensation.

As new methods of improving agricultural productivity are implemented and the recent trend in increasing irrigated acreage drops, the potential exists to make a major structural change in recent water use trends in the five water-short regions. This structural change could reduce the likelihood that shortages will emerge. As pointed out in Chapter 5, if irrigation water usage can be held at 1985 levels, shortages will disappear in the Rio Grande, Upper Colorado, and Great Basins. In California, holding irrigation water use at 1985 levels reduces the deficit enough that conservation in other uses will remedy the problem. The major impact of holding irrigation water usage at current levels is that irrigation will no longer be the primary impetus for growth in the agricultural economy in these regions; it will instead become a constraint. In the Lower Colorado basin, holding irrigation water usage at 1985 levels will not eliminate most shortages.

FREER WATER MARKETS WILL HELP

What is the most efficient way of keeping irrigation water usage at current levels in the Rio Grande, Upper Colorado, Great Basin, and California regions? Also, what is the most efficient method of reducing irrigation water usage in the Lower Colorado region?

The nation's economic system is predicated on allowing the market to function and induce changes in resource allocations. Seeking a market solution should be the first priority. Because irrigation water is the lowest-valued offstream water use, a freely-functioning and reasonably competitive market should help water move from irrigation to higher-valued offstream uses. It is too early to determine if changing to fair market pricing for water and lifting market constraints will be sufficient government intervention to ease projected shortages in the former four regions. Changing to fair market pricing will probably not induce sufficient change in irrigation water use in the Lower Colorado region to eliminate the projected shortage. Widespread and strong water conservation measures may also be necessary.

Without changes in water pricing and institutional arrangements, the projected shortages will probably occur. Current institutional frameworks that tie water rights to real estate and that mandate using water or losing the right to it provide the farmer with few options and little flexibility. These frameworks are protectionist and designed to stimulate expansion in demand—the opposite of what is needed to ease shortages. The current crop-surplus situation and Appraisal acreage projections hardly merit further expansion of crop production on the basis of economics. Non-price actions can be taken to help avoid shortages, but the effect will be to further constrain free market functioning. Farmers need flexibility to respond to clear market signals for crops and water in ways that best fit their short- and long-term operations. Being able to buy and sell water in competitive markets could provide the additional flexibility needed. For example, being able to sell water rights separate from land may enable some farmers to liquify one of their farm's major assets yet still remain a viable enterprise using new crops and varieties better suited to semi-arid, dry-land farming. To help free markets for

water, state and federal agencies need to consider the following policy issues:

— Should water markets be decontrolled to ease projected water shortages? Should water rights be separated from real estate so water and land can be sold independently?

— How far should water prices be allowed to rise and what will be the remaining imbalance between demand and supply at that price? Can non-price actions be taken to close the remaining gap? What will be the impacts of alternative courses of action on current and potential future water users?

— To what extent should cross-compliance measures be used to promote water conservation? Should subsidy payments be made on crops grown with subsidized water? Should receipt of crop subsidy payments be tied to an approved water conservation plan?

SOCIAL PREFERENCES ABOUT WATER USE PRIORITIES ARE CHANGING

The major impetus for easing water shortages is to assure sufficient water to meet society's needs. Historically, the first approach often tried in such situations was to increase supplies rather than face the reality that resources may be limited. Some water interests may still advocate such an approach through modification of vegetation, redistribution of high mountain snowpack, and weather modification. These approaches are attempts to retain established water use structures and institutions. However, as society and the economy have become more urbanized, the voting population has become progressively less sensitive to agricultural issues and concerns. Urban/suburban voters are demonstrating concern about the environment in terms more relevant to their lifestyles—they want fish and wildlife populations and recreation opportunities preserved. Consequently, if water shortages become more prevalent and affect urban/suburban lifestyles in terms of having less water-based recreation and fewer places to go fishing, political support will grow at the state level for changing the doctrine of prior appropriation. The priority of beneficial uses will change to non-agricultural uses. The question no longer is *will* the shift in water rights emphasis occur, but *when* and *how fast*.

Government programs to ease shortages that seek to perpetuate the status quo of appropriations priorities will increasingly come in conflict with social preferences. The trend in voter preferences suggests that suburban/urban interests are forcing changes in water use priorities. The effect is that irrigation will probably cease to enjoy its current water use priority. Evidence of this change is being observed. The Census of Agriculture shows areas where the decline of agricultural irrigation is largest. These are the areas where urban growth is fastest. Clearly, urban interests are forcing water use changes.

In the southern Rocky Mountain region, a water rights market appears to be emerging. Involvement by state water agencies varies—some encourage open market functioning while others strongly defend the existing water rights holder. Regardless of state agency involvement, water rights are generally shifting from agricultural to municipal and industrial use. Instream water uses are being recognized more and more in state courts.

REVERSING TRENDS IN WETLANDS LOSSES

The federal government has passed a number of laws over the past 50 years to encourage wetlands preservation. The Migratory Bird Hunting and Conservation Stamp program provided millions of dollars for wetlands conservation. Other incentive programs were also passed. The latest wetlands census indicates these programs have been unable to stem the tide; 300,000 acres of wetlands continue to be lost annually. The Food Security Act's swampbuster provision is another example. If someone not engaged in agriculture wants to convert wetlands to a non-agricultural use, the provision will not deter conversion. To reverse the trend in wetlands losses, incentive programs need to be strengthened. Plainly put, more money needs to be made available to conserve wetlands—a difficult task given the nation's current fiscal situation. A step that will not cost the government money is to change income tax provisions encouraging wetlands conversion, as outlined in Chapter 8.

State and local governments also can do more. Many local property tax administration policies contribute to wetlands conversions. In other jurisdictions, policies have begun to change. For example, "current use" valuation provisions are used in some areas to protect and encourage continuation of certain land uses such as forestry or crop production. Current use provisions assess land value based upon current use and not the highest-and-best use of the land. As long as landowners engage in forest management, for example, they retain the assessed value of forest land in spite of the potential land use for some higher-valued purpose. Similar provisions are being enacted for farmland near rapidly growing urban areas. If current-use valuation provisions were extended to wetlands which normally generate less income per acre than cropland, this would have a significant effect upon reversing the trend in wetlands losses.

QUESTION 2:

WHAT SHOULD BE THE MISSION OF THE NATIONAL FORESTS IN PRODUCTION OF WATER AND OTHER WATERSHED RESOURCES?

The discussion of question 1 highlighted policy issues about water yield augmentation.

Because 80% of the West's water emanates from national forests, the Forest Service will continue to play a role in diversion, storage, and development of water resources. These objectives will probably be emphasized to a greater extent in the remainder of this century than augmenting water yields from forest land.

Maintaining high-quality water in streams originating in or passing through national forests will become a top Forest Service priority.

MAINTAINING AND IMPROVING WATER QUALITY

There will be increasing concern about the Forest Service's ability to maintain high-quality water in streams originating in and passing through national forests. As concerns mount about skyrocketing costs of removing pollutants, emphasis will increasingly be placed on keeping water pure. Controlling sediment, the biggest nonpoint-source pollution threat from silvicultural and range management activities, will be a high priority. Implementing BMPs is the conventional approach to controlling erosion and protecting water quality. The Federal Facilities Compliance Program is placing renewed emphasis on cleaning up point- and nonpoint-source pollution from federal facilities. Rehabilitation and restoration of eroding watersheds is a major concern. The fate of chemicals (fertilizers and pesticides) applied to forests and rangelands is also a concern.

A shift in ownership of senior water rights is underway in the West. In many states, especially those where shortages are likely to emerge, municipalities are acquiring more senior rights from irrigators. Municipalities prefer to pay costs of diverting and transporting clean water rather than paying for treating water to render it potable. Once senior rights are secured, municipalities will become vocal proponents of maintaining high water quality. Thus, local governments are going to play an increasingly prominent role in reviewing land management decisions for water quality and quantity impacts. Further, these local governments may be located some distance from the national forest, so working relationships may need to be built where close ties have not existed in the past.

ENSURING SUITABLE INSTREAM FLOWS

Ensuring suitable instream flows for fish and wildlife habitat and for recreation has emerged as an issue and will become increasingly important in the coming decades. The shift in social priorities for water use will elevate concern about instream flows.

Serving instream flow needs will require close cooperation with state agencies dealing with water development, natural resources, fish, and wildlife. New memoranda of understanding may be needed to formalize cooperation. Partnerships with interest groups could be explored as a way of solidifying support for ensuring suitable flows. Obtaining interest group participation in building and maintaining fish habitat improvements is one example of help interest groups can provide.

MANAGING RIPARIAN AREAS

Riparian areas are at the interface between land areas and streams. These areas represent the last line of defense against sediment and other pollutants reaching streams and also play a significant role in providing habitat for fish and wildlife and in regulating runoff. Demands placed on riparian areas to help reduce nonpoint-source pollution will gain importance. Their use in regulating runoff also helps mitigate damages from minor floods. Management of riparian areas will become more intensive.

Integrated resource management will become more important over time. Watershed condition information will play an important role in bringing integrated resource management into broader use. Riparian areas will be located where integrated resource management is practiced most intensively. Thus, on many national forests, riparian areas are where integrated management will be practiced initially.

LONG-TERM MONITORING AND EVALUATION SITES

An important tool for solving complex ecological problems such as determining effects of acid deposition and ozone on forests and rangelands is having long-term trend data available. An important component of collecting long-term trend information is identifying sensitive areas and collecting data needed to understand ecosystem functioning. Without background information on how the ecosystem functioned before pollution, it is very difficult to determine effects of the pollutants after they begin to influence the ecosystems.

The most important obstacle to overcome in establishing long-term monitoring and evaluation sites is that it takes many years before the payoff. While essential baseline data is being collected and costs are incurred, benefits are still some years away. It is often tempting to postpone or cancel data collection, especially when budgets tighten. Postponement may be viewed as wise budgeting, but could have large social costs. Data may lose its ability to contribute toward solving major environmental problems.

The Forest Service makes periodic investments in human resources by providing training and varied assignments to prepare employees for management challenges. Making investments in beginning long-term data records now can also help prepare for solving more challenging questions in the future.

Establishing long-term monitoring and evaluation sites is more than a research task. National forest managers need information on long-term ecological trends to help prepare plans. Long-term trend data is essential for constructing a feedback loop for managers by indicating how they can learn from decisions and experience. Long-term trend information will also make possible cumulative effects evaluations over time. To make these analyses possible, planning for monitoring programs should be sensitive to two key elements: managers should decide on specific objectives for the monitoring process; and a statistically valid experimental design should be planned that responds to the objectives. Only then will long-term data collected be helpful in maintaining a quality environment.

Because of isolation from urban areas, parts of national forests are often left untouched by some pollutants affecting developed and populated areas. Wildernesses are important because they provide sites where baseline water quality information can be collected. However, locations outside formally-designated wilderness exist where vegetation management can provide the most important long-term data on environmental effects of watershed and water quality management. Long-term monitoring and evaluation programs can provide improved management information for land ownerships.

QUESTION 3: SHOULD POLICIES FOR MANAGEMENT OF NATIONAL FOREST WATERSHEDS VARY AMONG REGIONS?

The key objectives of national forest management—maintaining water quality; ensuring suitable flows in streams for fish, wildlife, and recreation; managing riparian areas; augmenting water yields—require consistent nationwide policies. But the targets and levels attained for each objective may differ considerably among Forest Service Regions, even though each is complying with the same policies.

East and West differences in water uses and water rights institutions are factors that justify varying policies among Regions. In the economic arena, conditions for optimality are often a function of prevailing institutional arrangements. What is most efficient under one scenario may be infeasible under a different scenario.

General policies that span differences in institutional frameworks allow for implementation within the varied contexts of local institutional arrangements. Policies should be consistent nationwide. Regions should have flexibility in developing objectives and implementing arrangements to deal with local institutions. For example, fish and wildlife species differ among Regions and require different practices to secure suitable minimum flows and flow levels. Yet all Regions can adhere to a consistent national policy about promoting habitat and managing riparian areas. Regions are the key organizational level for translating national policies and objectives into activities tailored to regional situations and institutions.

The concept of cumulative effects is becoming more important in national forest management. The idea is that while some effects may be innocuous on a local basis or for an individual project, the sum of all effects is unacceptably high when considered on a watershed, regional, or national basis or for all projects. Nonpoint-source pollution is an item whose cumulative effects have become very important for watershed managers. Regions could assume a lead role in establishing tolerable levels of cumulative effects for sediment generation and then

monitor the situations on national forests to assure that the cumulative effect is within limits.

QUESTION 4: HOW SHOULD MULTIPLE-USE RELATE TO WATER AND WATERSHED MANAGEMENT ON NATIONAL FORESTS?

Multiple-use is an important concept for watershed management even though the term has become politicized in recent years. The importance of multiple-use from a watershed standpoint relates to the historical approach taken by water supply firms and municipalities. This approach is to declare water supply watersheds off limits for public use and most vegetation management practices. If the public is excluded and vegetation remains undisturbed, water quality will remain high and risk of contamination and associated treatment costs will be low. This approach to obtaining potable supplies from watersheds originated at the turn of the century before chlorination and filtration were used. The cause of contamination was understood; how to clean it up was not and preventing contamination was stressed. Although municipal supplies are routinely disinfected today, some organisms such as *giardia* bacteria are remarkably resistent to chlorination and preventing contamination remains a public health challenge.

As senior water rights are acquired by municipalities, this historical approach will be recommended to public land managers as a way of guaranteeing high quality water supplies. For example, management guidelines are more restrictive for the watershed where Boulder, Colorado obtains its water supplies than are management guidelines for the nearby Indian Peaks Wilderness.

It is very important for the Forest Service to demonstrate that other resources on watersheds can be managed while still maintaining high-quality water. Areas should be identified where management activities such as recreation, grazing, or timber harvesting pose high risks to water quality. Unless greater sensitivity is demonstrated in integrating resource management to protect pristine water supplies, management options will become increasingly constrained as municipalities acquire larger numbers of senior water rights. If this happens, multiple-use will become an anachronism for watershed managers.

QUESTION 5: WHAT IS THE FOREST SERVICE MISSION IN PRODUCING WATER AND OTHER WATERSHED RESOURCES ON NONINDUSTRIAL PRIVATE LANDS?

There are three ways the Forest Service can provide assistance in the production of water and related watershed resources on nonindustrial private lands: improving water quality, restoring and protecting riparian habitat, and helping to reduce flood damages.[1] All three kinds of assistance will lead to improvements in watershed conditions.

IMPROVING WATER QUALITY

Private forests are key in the fight to reduce nonpoint-source pollution. Chapter 8 pointed out that lack of financial incentives and knowledge were two major obstacles to private landowners using BMPs for pollution control. BMPs are often not in the financial interest of landowners; however BMPs for silvicultural activities are generally known.

Financial assistance programs are in place. They are, however, inadequate to meet the needs of nonpoint-source pollution control. Cleaning up nonpoint-source pollution has emerged as a larger, more difficult, and more costly task than imagined when the Clean Water Act was passed. Additional funds could be provided for the forestry portion of the Agricultural Conservation Program and for water quality aspects of timber production under the Forestry Incentives Program (FIP). More funding is needed under both programs to attract wider participation by landowners. More money per landowner is also needed to cover additional expenses of BMPs. More assistance is needed to make landowners aware of the reforestation income tax credit and how they can use that provision to help pay for water quality protection and improvement.

Not only is financial and technical assistance needed to employ BMPs as part of current timber harvesting and regeneration activities, but assistance is also needed to restore and rehabilitate abused areas. For example, strip mines worked in the early part of this century and long since abandoned still emit sediment and other pollutants. Research demonstrates that planting abandoned strip mines to mixtures of trees and legumes is an effective way to rehabilitate the land, rebuild soil productivity, reduce nonpoint-source pollution, and restore productive watershed conditions. Assistance is needed to help cure problems created by past land uses.

Technical assistance is also needed for landowners switching from agricultural to forestry or range management to reduce agricultural nonpoint-source pollution. The Conservation Reserve Program is providing impetus for farmers with erodible land to switch from agricultural crops to trees or grass. In return for keeping land in trees or grass for a decade, the landowner receives annual payments from the Department of Agriculture.

Landowners need help weighing the merits of removing erodible land from crop production and in choosing between trees or grass as permanent cover. While receiving Conservation Reserve payments, the landowner cannot cut timber or harvest forage from enrolled lands. The landowner can, however, lease the land for hunting. In addition to providing technical assistance on timber production, assistance could be provided on how to increase wildlife populations and thereby hunting lease rates. The more income landowners obtain from not growing crops, the lower the incentive to convert land back to agriculture. This also lowers the chance that the land will contribute to erosion problems in the future.

RESTORING AND PROTECTING RIPARIAN AREAS

Many private landowners are unaware of the importance of riparian areas in preventing nonpoint-source pollution, reducing flood flows, and maintaining productive watersheds. Additional support is needed for using BMPs and the Conservation Reserve Program to establish streamside management zones on private lands. Information and education programs are needed that provide management information on how to integrate resource management and accompanying benefits.

REDUCING DOWNSTREAM FLOOD DAMAGES

Watershed rehabilitation efforts on private lands can increase rainfall infiltration rates and moisture-holding capacity of soils, thereby improving watershed condition. Both actions help retard runoff. If runoff is slowed, peak flows are reduced and less sediment is carried offsite. Trees are especially effective in promoting infiltration and slowing runoff.

Fire protection assistance is needed to keep vegetation growing on important watersheds. Watershed importance is determined by the magnitude of off-site damages that sediments and flood water could cause if vegetation were destroyed. The proliferation of dwellings on headwater flood plains is increasing the potential damage from flooding and fire. Maintaining vegetation on watersheds that would otherwise have rapid runoff is an important part of flood damage reduction efforts. When fire damages the vegetation, the emergency watershed program can provide assistance for quick revegetation.

Reversing the trend in wetlands conversions is also an important part of reducing flood damages. Wetlands provide temporary storage of flood water and slow flood water velocity. Preventing conversion of wetlands is a major reason for the swampbuster provision of the Food Security Act of 1985.

The impetus for conversion is often inability to obtain income from wetlands. Technical and financial assistance is needed so landowners can earn returns from not converting wetlands to other uses. Technical assistance should include not only silvicultural assistance, but also managing land for wildlife.

QUESTION 6:

WHAT IS THE MISSION OF FOREST SERVICE RESEARCH PROGRAMS IN PRODUCING NEW INFORMATION AND TECHNOLOGY NEEDED FOR WATERSHED AND WATER QUALITY MANAGEMENT?

The implications, opportunities, and obstacles outlined in this report identify two interrelated missions for watershed and water quality management research.

CUMULATIVE EFFECTS

Cumulative effects are an important research area for the Forest Service. Small disturbances distributed across a watershed may appear innocuous, yet their cumulative effect on downstream water uses may be substantial.

Disturbances distributed spatially across a watershed are important. For example, small timber harvest areas may each produce sediment. They may be so well scattered that they are not objectionable on visual grounds or in terms of the sediment generated at each harvesting location. The road network that connects them, however, may have a greater adverse effect upon the cumulative erosion in the watershed than all harvest sites put together.

Disturbances may also result from events distributed over time. Uneven-aged timber management is often advocated as less visually offensive than clearcutting. From a sediment generating perspective, frequent cutting and skidding may generate more sediment over time than clearcutting and artificial regeneration. For example, continual small harvests can generate enough sediment to cause lower respiration and reproduction rates in fish. This may cause less vigorous and lower numbers of fish for a longer time than two or three site entries over a rotation.

Research is needed into sediment generation and transport mechanisms and differences in rates from varied land management activities and their cumulative effects upon water quality and aquatic organisms. This information is essential for developing and testing new BMPs and technology to improve existing BMPs. One major need is research on keeping erosion under control after roads are constructed across slopes. Improving revegetation of road cuts and fills with native vegetation is important. When sites disturbed are located at high elevations or in semi-arid areas, native plants often grow slowly. Asexual propagation of alpine species at lower elevations for revegetation purposes has not been extensively studied. Because high-elevation watersheds will become more critical for water supply purposes, research with species common at high elevations will become more important.

The cumulative effects of acid deposition and chemical buildups in watersheds need to be explored. Few long-term background data exist to evaluate temporal variability in rainfall constituents. Monitoring stations number nearly 200 but records are just a decade old.

Differences exist within the scientific community over the roles of acids versus ozone in decline in forest growth and in stream and lake chemistry. Some differences may arise from variability in rainfall constituents by season and geographic location. International cooperative work should continue among scientists at government laboratories and universities here and abroad.

Chemical buildups in watersheds are an issue of emerging importance. Nutrient and energy cycling are related to soil and site productivity. Residuals from fertilizers and pesticides must be fully explored. Differences in rates of movement within ecosystems should be studied as related to chemical composition and transportability. For example, is the chemical persistent or does it break down rapidly? If it breaks down, are decomposed products more or less mobile and more or less harmful than the original chemical? Does the chemical

adsorb readily onto soil colloids and does this affect chemical activity? If adsorbed, what are its effects on aquatic ecosystems washed into a stream? Many of these questions are asked about agricultural chemicals. Given the similarities between chemicals applied to forests, rangeland, and cropland, a comprehensive examination of nutrients and other chemicals and their effects on nonpoint-source pollution in various ecosystems should be performed.

Increasing complexity of problems such as acid deposition and chemical buildups in watersheds point to the value of long-term records. Thus, the value of research locations such as Hubbard Brook Experimental Forest, New Hampshire; Fraser Experimental Forest, Colorado; Coweeta Hydrologic Laboratory, North Carolina (50 years old); Crossett Experimental Forest, Arkansas (60 years old); and the Wind River Experimental Forest, Wyoming (70 years old) is better understood today. Today, the Forest Service maintains 84 experimental forests across the nation. However, the agency had a total of 113 experimental forests at one time or another this century; 16 were lost in the 1960s. If long-term records such as those available on the 84 experimental forests are allowed to lapse, the capability to answer difficult and complex forest related questions nay also be lost.

The final cumulative effect needing research is defining instream flows necessary to support various instream water uses in different situations. Each water withdrawal affects water volume in a stream and the suitability of that stream for fish and wildlife habitat and recreation. Considered alone, most proposed withdrawals or diversions are not large enough to cause significant impacts on suitability of instream flows. However, when all withdrawals and diversions are considered, the effects of one additional permit to withdraw or divert water may be substantial.

Land managers and owners are frequently asked to make judgments about levels of instream flows needed to avoid detrimental effects on instream water uses. Little information is available to guide these decisions. Research to develop procedures for quantifying and evaluating cumulative effects of withdrawals and diversions will be helpful in the long-term. Developing initial estimates of suitable flows needed under certain conditions could be most helpful in the short-term.

MAINTAINING LAND PRODUCTIVITY

Maintaining land productivity was mandated by the National Forest Management Act of 1976. The Forest Service's research mission could focus on soil productivity to help fulfill agency obligations under that act.

The objective of soil productivity research is to develop an ability to use site characteristics to predict the productivity of a site for a variety of resources. Work is underway to predict timber outputs from site characteristics. A major task is to define nutritional needs of major commercial timber species. For the most part, little is known about this subject. The most knowledge exists for loblolly pine, but many gaps still exist.

Relationships between soil productivity and agricultural crops are much better known than those between soil productivity and trees. Some results are available for forage from agricultural research. Interdisciplinary teams have been responsible for many advances in the agricultural field, particularly in plant breeding and seed development. A similar interdisciplinary approach may prove useful for soil productivity research in forested ecosystems. This team, having skills in genetics, silviculture, soil science, and ecological modeling could take advantage of the synergy among specialties. Not only must models be constructed, but validation methods also need to be developed.

NOTES

1. Providing technical and financial assistance to nonindustrial private forest landowners has been a Forest Service responsibility for many years. Providing assistance to rangeland owners is an SCS responsibility.

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The data displayed in these tables for 1960 to 1985 come from USGS Circulars on estimated water use (MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972, Murray and Reeves 1977, Solley et al. 1983, Solley et al. 1988). Projections of water use from 2000 to 2040 are Forest Service estimates based upon regression equations reported in Appendix B.

The demand statistics in these tables differ in two important ways from the demand statistics for water use reported in the Appraisal. First, statistics in this report include the most recent data; estimates of water use in 1985. The 1980 data were the latest used for making water demand projections in the Appraisal. Second, projections in this report are based on historical relationships among determinants of water demand and recent trends in how those relationships have changed. In contrast, Appraisal demand projections are based on assumed future changes in relationships among demand determinants. Consequently, the scenario projected in this report is a continuation of recent trends while that projected in the Appraisal is the *most likely* scenario based on the assumed future changes in demand determinants and their relationships.

Tables A.1 to A.6 summarize freshwater withdrawals by use. Each table shows the amount of water withdrawn by water source (groundwater, surface water, and wastewater, where applicable) by water resource region. Wastewater withdrawal data are only available for irrigation and industrial use. Water resource regions were defined by the Water Resources Council (fig. A.1). Regions divide the continental U.S. into 18 major hydrologic basins. Data are also shown for Alaska, Hawaii, and the Caribbean.

Tables A.7 to A.12 summarize freshwater withdrawals by use and water source and present information by Forest Service Region. Administration of the National Forest System is decentralized by 9 Regions (fig. A.2). Water withdrawal and consumption information by state were obtained from USGS and were then combined into Forest Service Regions. For display purposes, Forest Service Regions were further aggregated into four geographic regions—North, South, Rocky Mountains, and Pacific Coast. The North is the Eastern Region. The South is the Southern Region, including Puerto Rico and the Virgin Islands. The Rocky Mountains contain the Northern, Rocky Mountain, Southwestern, and Intermountain Regions. The Pacific Coast contains the California (including Hawaii), Pacific Northwest, and Alaskan Regions.

Tables A.13 to A.18 summarize consumption by use for Forest Service Regions and water resource regions. Consumption data is not available by water source.

Figures A.3–A.16 illustrate trends in withdrawals by water use category and by source, groundwater versus surface water.

Figure A.1.—Water resource regions

Figure A.2.—Assessment and Forest Service Regions.

Table A.1.—Freshwater withdrawals (million gallons per day) for thermoelectric steam cooling use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	6	0	1	1	1	0	0	0	0	0	0
Mid-Atlantic	3	8	100	170	110	44	60	59	59	58	58
South Atlantic-Gulf	17	17	32	91	88	35	33	33	33	32	32
Great Lakes	0	0	38	64	30	12	21	21	20	20	20
Ohio	19	40	54	32	52	21	22	22	21	21	21
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	7	9	290	34	13	5	53	53	52	52	51
Lower Mississippi	21	76	66	27	54	21	23	23	23	22	22
Souris-Red-Rainy	3	1	1	0	1	0	0	0	0	0	0
Missouri Basin	5	61	310	310	48	19	106	104	103	102	102
Arkansas-White-Red	37	42	46	56	70	28	27	27	27	26	26
Texas-Gulf	301	320	51	32	30	12	18	18	17	17	17
Rio Grande	179	190	15	22	15	6	8	8	8	8	8
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	18	19	44	38	45	18	20	20	20	19	19
Great Basin	0	0	4	4	5	2	2	2	2	2	2
Pacific Northwest	0	0	0	7	5	2	2	2	2	2	2
California	290	300	300	380	890	352	248	245	242	240	239
Alaska	0	1	1	2	8	3	2	2	2	2	2
Hawaii	14	31	82	140	130	51	56	55	54	54	54
Caribbean	0	0	0	0	3	1	0	0	0	0	0
Total Groundwater	920	1115	1435	1410	1598	633	703	694	686	679	676
Surface Water											
New England	620	870	1900	1900	2300	2041	2456	2734	3012	3289	3567
Mid-Atlantic	8100	10300	15000	14000	15000	13312	16019	17830	19641	21452	23262
South Atlantic-Gulf	8400	10900	15000	18000	19000	16861	20291	22585	24879	27173	29466
Great Lakes	17500	20000	26000	25000	27000	23961	28835	32095	35354	38614	41872
Ohio	16000	20000	27000	27000	30000	26623	32039	35661	39283	42904	46525
Tennessee	5600	5900	6100	8700	9300	8253	9932	11055	12178	13300	14423
Upper Mississippi	8200	13000	12000	13000	16000	14199	17087	19019	20951	22882	24813
Lower Mississippi	930	1800	4000	6000	7700	6833	8223	9153	10083	11012	11941
Souris-Red-Rainy	0	64	140	190	53	47	57	63	69	76	82
Missouri Basin	2200	2200	3000	3900	8100	7188	8650	9628	10606	11584	12562
Arkansas-White-Red	3130	1700	1900	2800	9900	8786	10573	11768	12963	14158	15353
Texas-Gulf	1877	2600	4700	7600	950	843	1015	1129	1244	1359	1473
Rio Grande	123	170	6	5	2	2	2	2	3	3	3
Upper Colorado	118	120	100	160	140	124	150	166	183	200	217
Lower Colorado	2	2	3	110	45	40	48	53	59	64	70
Great Basin	76	170	130	78	120	106	128	143	157	172	186
Pacific Northwest	7	5	26	29	23	20	25	27	30	33	36
California	140	660	1200	1100	1100	976	1175	1308	1440	1573	1706
Alaska	86	1	68	18	22	20	23	26	29	31	34
Hawaii	12	41	46	32	9	8	10	11	12	13	14
Caribbean	4	0	0	0	0	0	0	0	0	0	0
Total Surface Water	73125	90503	118319	129622	146764	130243	156738	174457	192176	209893	227606
Total Withdrawals											
New England	626	870	1901	1901	2301	2030	2442	2716	2991	3266	3541
Mid-Atlantic	8103	10308	15100	14170	15110	13329	16035	17838	19642	21446	23249
South Atlantic-Gulf	8417	10917	15032	18091	19088	16838	20256	22535	24813	27092	29370
Great Lakes	17500	20000	26038	25064	27030	23844	28684	31911	35137	38364	41591
Ohio	16019	20040	27054	27032	30052	26510	31891	35478	39066	42653	46240
Tennessee	5600	5900	6100	8700	9300	8204	9869	10979	12089	13200	14310
Upper Mississippi	8207	13009	12290	13034	16013	14126	16993	18904	20816	22727	24639
Lower Mississippi	951	1876	4066	6027	7754	6840	8229	9154	10080	11005	11931
Souris-Red-Rainy	3	65	141	190	54	48	57	64	70	77	83
Missouri Basin	2205	2261	3310	4210	8148	7188	8647	9619	10592	11565	12537
Arkansas-White-Red	3167	1742	1946	2856	9970	8795	10580	11770	12960	14151	15341
Texas-Gulf	2208	2920	4751	7632	980	864	1040	1157	1274	1391	1508
Rio Grande	272	360	21	27	17	15	18	20	22	24	26
Upper Colorado	117	120	100	160	140	123	149	165	182	199	215
Lower Colorado	21	21	47	148	90	79	96	106	117	128	138
Great Basin	76	170	134	82	125	110	133	148	162	177	192
Pacific Northwest	7	5	26	36	28	25	30	33	36	40	43
California	430	960	1500	1480	1990	1755	2112	2349	2587	2824	3062
Alaska	86	2	69	20	30	26	32	35	39	43	46
Hawaii	26	72	128	172	139	123	148	164	181	197	214
Caribbean	4	0	0	0	3	3	3	4	4	4	5
Total Withdrawals	74045	91618	119754	131032	148362	130876	157441	175151	192862	210572	228282

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.2.—Freshwater withdrawals (million gallons per day) for irrigation use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	0	10	20	12	8	6	6	6	7	7	7
Mid-Atlantic	48	82	77	150	97	74	73	76	80	82	84
South Atlantic-Gulf	322	1200	1300	1300	2000	1520	1501	1576	1645	1692	1733
Great Lakes	15	24	37	44	180	137	135	142	148	152	156
Ohio	3	6	8	10	88	67	66	69	72	74	76
Tennessee	2	1	2	2	3	2	2	2	2	3	3
Upper Mississippi	27	60	69	100	350	266	263	276	285	296	303
Lower Mississippi	590	1100	2000	3300	4800	3649	3602	3782	3947	4061	4159
Souris-Red-Rainy	0	2	8	26	46	35	35	36	38	39	40
Missouri Basin	2226	2700	4500	8800	11000	8362	8256	8667	9046	9306	9532
Arkansas-White-Red	2260	8000	5900	7900	8400	6386	6304	6619	6908	7107	7279
Texas-Gulf	6346	5800	5000	6000	3900	2965	2927	3073	3207	3300	3380
Rio Grande	2954	2700	2000	1900	1600	1216	1201	1261	1316	1354	1386
Upper Colorado	11	14	53	60	81	62	61	64	67	69	70
Lower Colorado	3189	4000	3900	4400	3900	2965	2927	3073	3207	3300	3380
Great Basin	760	890	760	1000	1000	760	751	788	822	846	867
Pacific Northwest	2900	3300	3000	4500	5100	3877	3828	4019	4194	4315	4419
California	8200	11000	16000	17000	18000	13684	13509	14183	14802	15229	15598
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	380	590	550	430	460	350	345	362	378	389	399
Caribbean	170	93	67	140	140	106	105	110	115	118	121
Total Groundwater	30403	41572	45251	57074	61153	56292	55575	58347	60894	62649	64167
Surface Water											
New England	10	16	60	45	45	46	46	49	53	55	58
Mid-Atlantic	33	40	50	84	150	152	154	165	176	185	193
South Atlantic-Gulf	476	2000	1100	1700	1800	1824	1842	1977	2108	2216	2320
Great Lakes	31	41	53	56	120	122	123	132	141	148	155
Ohio	9	18	27	24	60	61	61	66	70	74	77
Tennessee	12	7	4	5	4	4	4	4	5	5	5
Upper Mississippi	16	25	35	42	29	29	30	32	34	36	37
Lower Mississippi	260	860	1200	1600	2900	2939	2968	3185	3396	3571	3737
Souris-Red-Rainy	13	23	4	16	18	18	18	20	21	22	23
Missouri Basin	11019	13000	14000	20000	18000	18240	18424	19767	21081	22163	23198
Arkansas-White-Red	2340	2200	2300	2100	2400	2432	2457	2636	2811	2955	3093
Texas-Gulf	806	1300	1100	1000	1600	1621	1638	1757	1874	1970	2062
Rio Grande	2294	3700	3500	2900	2700	2736	2764	2965	3162	3324	3480
Upper Colorado	5948	6400	7800	3700	7400	7499	7574	8126	8667	9112	9537
Lower Colorado	1952	2100	2600	3100	3700	3749	3787	4063	4333	4556	4768
Great Basin	4400	3900	5100	5000	4900	4965	5016	5381	5739	6033	6315
Pacific Northwest	16000	23000	24000	24000	24000	24320	24566	26356	28109	29551	30930
California	7800	15000	18000	19000	20000	20266	20472	21963	23424	24626	25775
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	540	570	680	520	450	456	461	494	527	554	580
Caribbean	110	160	73	120	180	182	184	198	211	222	232
Total Surface Water	54069	74360	81686	85012	90456	85767	86635	92947	99129	104215	109080
Wastewater											
New England	0	1	0	0	0	0	0	0	0	0	0
Mid-Atlantic	1	0	0	0	0	0	0	0	0	0	0
South Atlantic-Gulf	0	0	0	0	0	0	0	0	0	0	0
Great Lakes	0	0	0	0	30	49	31	28	24	21	19
Ohio	0	0	0	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	0	0	0	0	0	0	0	0	0	0	0
Lower Mississippi	0	0	0	0	0	0	0	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	24	0	88	80	2	3	2	2	2	1	1
Arkansas-White-Red	15	0	6	2	15	24	16	14	12	11	9
Texas-Gulf	9	5	14	31	55	89	57	51	44	39	35
Rio Grande	33	18	17	20	0	0	0	0	0	0	0
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	2	57	5	58	6	10	6	6	5	4	4
Great Basin	48	51	53	5	4	6	4	4	3	3	3
Pacific Northwest	0	3	6	9	17	28	18	16	14	12	11
California	430	400	120	160	150	244	156	138	121	107	95
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	0	0	57	0	0	0	0	0	0	0	0
Caribbean	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	562	535	366	365	279	453	290	257	225	199	176
Total Withdrawals											
New England	10	27	80	57	53	42	42	45	47	49	51
Mid-Atlantic	82	122	127	234	247	238	238	253	268	279	290
South Atlantic-Gulf	798	3200	2400	3000	3800	3656	3656	3888	4111	4286	4449
Great Lakes	46	65	90	100	330	478	478	508	537	560	582
Ohio	12	24	35	34	148	101	101	107	114	118	123
Tennessee	14	8	6	7	7	18	18	19	20	21	22
Upper Mississippi	43	85	104	142	379	532	532	566	598	624	647
Lower Mississippi	850	1960	3200	4900	7700	6500	6499	6912	7309	7620	7910
Souris-Red-Rainy	13	25	12	42	64	159	159	169	179	186	193
Missouri Basin	13269	15700	18588	28880	29002	26465	26463	28144	29759	31024	32206
Arkansas-White-Red	4615	10200	6206	10002	10815	9869	9868	10495	11097	11569	12010
Texas-Gulf	6537	7105	6114	7031	5555	8744	8743	9299	9832	10250	10641
Rio Grande	5905	6418	5517	4820	4300	3924	3924	4173	4412	4600	4775
Upper Colorado	5613	6414	7853	3760	7481	6827	6826	7260	7676	8003	8307
Lower Colorado	5388	6157	6505	7558	7606	6941	6940	7381	7804	8136	8446
Great Basin	5208	4841	5913	6005	5904	5388	5388	5730	6059	6316	6557
Pacific Northwest	18900	26303	27006	28509	29117	26570	26568	28255	29877	31147	32333
California	16430	26400	34120	36160	38150	34813	34810	37021	39146	40810	42364
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	920	1160	1287	950	910	830	830	883	934	973	1011
Caribbean	280	253	140	260	320	417	417	443	469	489	507
Total Withdrawals	84933	116467	127303	142451	151888	142512	142500	151551	160248	167063	173423

Source: Data for 1960 through 1980 from USGS Circulars. In addition to the irrigation of crops, this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional nonagricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data

Table A.3.—Freshwater withdrawals (million gallons per day) for municipal central supplies in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	170	260	330	280	330	421	565	679	795	890	949
Mid-Atlantic	670	890	1100	1300	1100	1402	1885	2263	2650	2966	3163
South Atlantic-Gulf	810	990	1300	1500	1900	2422	3256	3910	4577	5124	5464
Great Lakes	363	400	700	460	440	561	754	905	1060	1187	1265
Ohio	400	510	620	700	730	930	1251	1502	1758	1969	2099
Tennessee	73	71	64	79	89	113	153	183	214	240	256
Upper Mississippi	410	570	870	1200	1100	1402	1885	2263	2650	2966	3163
Lower Mississippi	210	270	390	470	610	777	1045	1255	1469	1645	1754
Souris-Red-Rainy	15	15	20	22	27	34	46	56	65	73	78
Missouri Basin	316	340	430	490	530	675	908	1091	1277	1429	1524
Arkansas-White-Red	265	310	250	370	320	408	548	658	771	863	920
Texas-Gulf	449	510	590	670	800	1020	1371	1646	1927	2157	2301
Rio Grande	141	160	180	280	240	306	411	494	578	647	690
Upper Colorado	12	19	28	26	23	29	39	47	55	62	66
Lower Colorado	148	230	250	320	370	472	634	761	891	998	1064
Great Basin	130	110	160	190	400	510	685	823	964	1079	1150
Pacific Northwest	350	410	460	460	530	675	908	1091	1277	1429	1524
California	1300	1900	1600	1700	1900	2422	3256	3910	4577	5124	5464
Alaska	8	12	24	35	23	29	39	47	55	62	66
Hawaii	74	100	120	170	180	229	308	370	434	485	518
Caribbean	7	19	34	59	75	96	129	154	181	202	216
Total Groundwater	6321	8096	9520	10781	11717	14933	20077	24110	28225	31597	33697
Surface Water											
New England	870	950	1100	1100	1200	1170	1638	1858	2071	2239	2341
Mid-Atlantic	3160	3140	4100	4000	4300	4193	5870	6659	7423	8023	8387
South Atlantic-Gulf	970	990	1400	1700	1900	1853	2594	2942	3280	3545	3706
Great Lakes	3000	3400	3700	2700	3500	3413	4778	5420	6042	6530	6827
Ohio	1100	1300	1500	1500	1500	1463	2048	2323	2589	2799	2926
Tennessee	240	180	240	250	320	312	437	496	552	597	624
Upper Mississippi	600	580	690	1800	820	800	1119	1270	1415	1530	1599
Lower Mississippi	170	230	220	280	310	302	423	480	535	578	605
Souris-Red-Rainy	18	21	25	26	30	29	41	46	52	56	59
Missouri Basin	510	630	590	720	850	829	1160	1316	1467	1586	1658
Arkansas-White-Red	360	420	490	570	1200	1170	1638	1858	2071	2239	2341
Texas-Gulf	490	460	550	690	2200	2145	3003	3407	3798	4105	4291
Rio Grande	100	94	130	74	74	72	101	115	128	138	144
Upper Colorado	37	34	30	51	100	98	137	155	173	187	195
Lower Colorado	73	66	140	190	350	341	478	542	604	653	683
Great Basin	140	160	160	190	410	400	560	635	708	765	800
Pacific Northwest	840	840	830	710	730	712	996	1130	1260	1362	1424
California	1400	2100	1800	2000	2200	2145	3003	3407	3798	4105	4291
Alaska	15	20	35	46	30	29	41	46	52	56	59
Hawaii	11	8	12	11	15	15	20	23	26	28	29
Caribbean	62	120	170	230	280	273	382	434	483	522	546
Total Surface Water	14166	15743	17912	18838	22319	21765	30466	34562	38527	41643	43532
Total Withdrawals											
New England	1040	1210	1430	1380	1530	1650	2265	2621	2971	3251	3466
Mid-Atlantic	3830	4030	5200	5300	5400	5822	7995	9250	10487	11473	12232
South Atlantic-Gulf	1780	1980	2700	3200	3800	4097	5626	6509	7380	8074	8608
Great Lakes	3363	3800	4400	3160	3940	4248	5833	6749	7652	8371	8925
Ohio	1500	1810	2120	2200	2230	2404	3302	3820	4331	4738	5052
Tennessee	313	251	304	329	409	441	606	701	794	869	926
Upper Mississippi	1010	1150	1560	3000	1920	2070	2843	3289	3729	4079	4349
Lower Mississippi	380	500	610	750	920	992	1362	1576	1787	1955	2084
Souris-Red-Rainy	33	36	45	48	57	61	84	98	111	121	129
Missouri Basin	826	970	1020	1210	1380	1488	2043	2364	2680	2932	3126
Arkansas-White-Red	625	730	740	940	1520	1639	2250	2604	2952	3230	3443
Texas-Gulf	935	970	1140	1360	3000	3235	4442	5139	5826	6374	6796
Rio Grande	245	254	310	354	314	339	465	538	610	667	711
Upper Colorado	41	53	58	77	123	133	182	211	239	261	279
Lower Colorado	229	296	390	510	720	776	1066	1233	1398	1530	1631
Great Basin	270	270	320	380	810	873	1199	1387	1573	1721	1835
Pacific Northwest	1190	1250	1290	1170	1260	1359	1865	2158	2447	2677	2854
California	2700	4000	3400	3700	4100	4421	6070	7023	7962	8711	9288
Alaska	23	32	59	81	53	57	78	91	103	113	120
Hawaii	85	108	132	181	195	210	289	334	379	414	442
Caribbean	69	139	204	289	355	383	526	608	689	754	804
Total Withdrawals	20487	23839	27432	29619	34036	36699	50392	58301	66100	72316	77100

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.4.—Freshwater withdrawals (million gallons per day) for industrial self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	130	140	180	200	180	81	111	128	147	166	187
Mid-Atlantic	630	700	1000	630	580	261	438	505	579	656	737
South Atlantic-Gulf	1140	1300	1500	1900	1800	809	1031	1188	1362	1542	1734
Great Lakes	421	360	300	300	630	283	244	281	322	365	410
Ohio	600	890	750	740	1300	585	553	638	731	828	930
Tennessee	230	49	45	140	97	44	56	64	74	84	94
Upper Mississippi	480	620	630	690	650	292	390	450	516	584	657
Lower Mississippi	450	470	980	950	1000	450	581	670	767	869	977
Souris-Red-Rainy	5	7	5	2	4	2	2	3	3	3	4
Missouri Basin	183	270	360	400	380	171	226	261	299	338	380
Arkansas-White-Red	310	400	250	290	320	144	170	197	225	255	287
Texas-Gulf	352	340	390	340	240	108	192	222	254	288	323
Rio Grande	78	75	110	84	16	7	42	48	55	62	70
Upper Colorado	5	8	12	28	23	10	12	14	16	19	21
Lower Colorado	75	110	170	210	160	72	107	123	141	160	180
Great Basin	110	65	85	120	130	58	66	77	88	99	112
Pacific Northwest	400	400	620	2100	2300	1034	995	1147	1314	1489	1674
California	300	480	410	390	430	193	244	281	322	365	410
Alaska	12	7	8	0	6	3	3	3	4	4	5
Hawaii	110	65	160	97	9	4	53	61	70	79	89
Caribbean	29	38	40	72	85	38	39	45	52	58	66
Total Groundwater	6050	6794	8005	9683	10340	4650	5555	6405	7339	8314	9345
Surface Water											
New England	1100	1100	1100	1300	1300	898	907	987	1064	1139	1212
Mid-Atlantic	2830	3200	5600	3700	2900	2003	2990	3255	3508	3755	3995
South Atlantic-Gulf	1970	1600	2100	2600	4100	2832	2157	2348	2530	2709	2882
Great Lakes	7200	8700	8300	6900	5100	3523	4976	5416	5837	6249	6647
Ohio	6600	7700	5100	5200	3700	2556	3431	3735	4025	4309	4584
Tennessee	1200	1000	1300	1500	2000	1382	1176	1281	1380	1477	1572
Upper Mississippi	1200	1000	1100	1100	2600	1796	1176	1281	1380	1477	1572
Lower Mississippi	940	2100	3100	3300	3200	2211	2353	2561	2760	2955	3144
Souris-Red-Rainy	80	98	73	31	5	3	27	29	31	34	36
Missouri Basin	280	180	160	120	300	207	142	155	167	179	190
Arkansas-White-Red	681	440	370	630	530	366	375	408	440	471	501
Texas-Gulf	819	570	1000	330	280	193	395	430	463	496	527
Rio Grande	11	8	97	9	0	0	26	28	30	33	35
Upper Colorado	28	30	52	63	580	387	165	180	194	208	221
Lower Colorado	25	27	42	58	86	59	46	50	53	57	61
Great Basin	200	140	130	120	370	256	152	165	178	191	203
Pacific Northwest	1700	1400	1100	1300	1400	967	931	1014	1093	1170	1244
California	64	85	48	55	58	40	39	43	46	50	53
Alaska	70	95	100	90	120	83	76	83	89	95	102
Hawaii	33	51	100	94	36	25	56	61	66	71	75
Caribbean	130	140	180	98	30	21	75	82	89	95	101
Total Suface Water	27161	29664	31152	28598	28675	19810	21673	23591	25425	27218	28955
Wastewater											
New England	0	0	0	0	0	0	0	0	0	0	0
Mid-Atlantic	70	130	130	150	160	120	266	312	359	406	453
South Atlantic-Gulf	0	0	0	0	0	0	0	0	0	0	0
Great Lakes	0	0	0	0	0	0	0	0	0	0	0
Ohio	0	0	0	0	0	0	0	0	0	0	0
Tennessee	0	0	0	0	0	0	0	0	0	0	0
Upper Mississippi	0	0	0	0	0	0	0	0	0	0	0
Lower Mississippi	0	0	0	0	0	0	0	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	0	0	0	0	0	0	0	0	0	0	0
Arkansas-White-Red	0	2	5	4	0	0	5	6	7	8	9
Texas-Gulf	0	2	1	5	0	0	4	4	5	6	6
Rio Grande	0	4	0	0	0	0	0	0	0	0	0
Upper Colorado	0	0	0	0	0	0	0	0	0	0	0
Lower Colorado	0	1	0	7	12	9	11	13	15	18	20
Great Basin	0	0	0	1	1	1	1	1	2	2	2
Pacific Northwest	0	0	0	0	0	0	0	0	0	0	0
California	1	1	4	2	9	7	9	11	12	14	15
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	0	0	9	0	10	8	11	13	15	18	20
Caribbean	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	71	140	149	169	192	144	308	362	416	471	525
Total Withdrawals											
New England	1230	1240	1280	1500	1480	928	996	1097	1199	1300	1401
Mid-Atlantic	3460	3900	6600	4330	3480	2182	3369	3712	4054	4397	4739
South Atlantic-Gulf	3110	2900	3600	4500	5900	3699	3273	3606	3939	4272	4604
Great Lakes	7621	9060	8600	7200	5730	3592	5034	5546	6057	6569	7081
Ohio	7200	8590	5850	5940	5000	3135	3926	4325	4724	5123	5522
Tennessee	1430	1049	1345	1640	2097	1315	1188	1309	1430	1551	1671
Upper Mississippi	1680	1620	1730	1790	3250	2038	1583	1744	1905	2066	2227
Lower Mississippi	1390	2570	4080	4250	4200	2633	2930	3227	3525	3823	4121
Souris-Red-Rainy	85	105	78	33	9	6	28	31	34	37	39
Missouri Basin	463	450	520	520	680	426	402	443	484	525	566
Arkansas-White-Red	991	840	620	920	850	533	559	616	672	729	786
Texas-Gulf	1168	910	1390	670	520	326	603	665	726	787	849
Rio Grande	106	83	207	93	16	10	74	81	89	96	104
Upper Colorado	29	38	64	91	583	365	173	190	208	225	243
Lower Colorado	104	137	212	268	246	154	170	187	204	222	239
Great Basin	310	205	215	240	500	313	223	246	269	291	314
Pacific Northwest	2100	1800	1720	3400	3700	2320	2062	2272	2482	2691	2901
California	364	565	458	445	488	306	325	358	391	424	457
Alaska	82	102	108	90	126	79	76	83	91	99	107
Hawaii	143	116	260	191	45	28	116	128	140	151	163
Caribbean	159	178	220	170	115	72	118	130	142	154	166
Total Withdrawals	33225	36458	39157	38281	39015	24460	27228	29996	32764	35532	38300

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data

Table A.5.—Freshwater withdrawals (million gallons per day) for domestic self-supplied use in the United States for 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	37	95	94	110	130	129	171	191	209	223	231
Mid-Atlantic	260	270	340	380	430	428	566	632	691	738	764
South Atlantic-Gulf	320	540	460	510	720	717	948	1058	1158	1235	1279
Great Lakes	290	260	270	280	270	269	356	397	434	463	480
Ohio	190	240	240	280	290	289	382	426	466	497	515
Tennessee	57	64	51	42	61	61	80	90	98	105	108
Upper Mississippi	160	190	200	190	290	289	382	426	466	497	515
Lower Mississippi	50	63	110	77	94	94	124	138	151	161	167
Souris-Red-Rainy	10	13	19	24	23	23	30	34	37	39	41
Missouri Basin	98	94	110	130	210	209	277	309	338	360	373
Arkansas-White-Red	69	98	88	100	130	129	171	191	209	223	231
Texas-Gulf	30	33	80	100	120	119	158	176	193	206	213
Rio Grande	9	10	20	25	33	33	43	49	53	57	59
Upper Colorado	1	4	6	6	15	15	20	22	24	26	27
Lower Colorado	1	10	24	36	37	37	49	54	59	63	66
Great Basin	14	26	37	28	32	32	42	47	51	55	57
Pacific Northwest	39	95	220	220	230	229	303	338	370	394	409
California	190	81	120	120	130	129	171	191	209	223	231
Alaska	5	6	4	6	11	11	14	16	18	19	20
Hawaii	6	0	0	0	4	4	5	6	6	7	7
Caribbean	2	1	0	2	5	5	7	7	8	9	9
Total Groundwater	1838	2193	2493	2666	3265	3251	4300	4800	5250	5600	5800
Surface Water											
New England	2	5	2	2	1	0	1	1	0	0	0
Mid-Atlantic	2	1	2	2	2	1	1	1	1	0	0
South Atlantic-Gulf	0	0	2	2	0	0	0	0	0	0	0
Great Lakes	10	10	7	4	3	1	2	1	1	1	1
Ohio	31	41	33	25	21	10	11	9	6	4	4
Tennessee	1	0	1	0	0	0	0	0	0	0	0
Upper Mississippi	17	16	6	8	10	5	5	3	2	2	2
Lower Mississippi	5	1	0	1	1	0	1	0	0	0	0
Souris-Red-Rainy	0	0	0	0	0	0	0	0	0	0	0
Missouri Basin	15	12	11	14	22	10	9	7	5	4	4
Arkansas-White-Red	5	6	6	7	25	12	9	7	4	3	3
Texas-Gulf	0	0	0	0	0	0	0	0	0	0	0
Rio Grande	0	0	1	1	1	0	1	0	0	0	0
Upper Colorado	14	2	1	1	43	20	13	10	7	5	5
Lower Colorado	0	0	0	0	0	0	0	0	0	0	0
Great Basin	2	1	1	1	4	2	1	1	1	1	1
Pacific Northwest	30	6	29	34	32	15	17	12	8	6	6
California	17	9	9	9	9	4	5	3	2	2	2
Alaska	1	2	2	3	0	0	1	0	0	0	0
Hawaii	2	0	0	0	0	0	0	0	0	0	0
Caribbean	9	4	3	18	3	1	5	3	2	2	2
Total Surface Water	163	116	116	132	177	83	80	60	40	30	30
Total Withdrawals											
New England	39	100	96	112	131	127	167	186	202	241	222
Mid-Atlantic	262	271	342	382	432	418	550	615	665	707	732
South Atlantic-Gulf	320	540	462	512	720	697	916	1025	1109	1178	1220
Great Lakes	300	270	277	284	273	264	347	389	420	447	462
Ohio	221	281	273	305	311	301	396	443	479	509	527
Tennessee	58	64	52	42	61	59	78	87	942	100	103
Upper Mississippi	177	206	206	198	300	291	382	427	462	491	508
Lower Mississippi	55	64	110	78	95	92	121	135	146	155	161
Souris-Red-Rainy	10	13	19	24	23	22	29	33	35	38	39
Missouri Basin	113	106	121	144	232	225	295	330	357	379	393
Arkansas-White-Red	74	104	94	107	155	150	197	221	239	254	263
Texas-Gulf	33	33	80	100	120	116	153	171	185	196	203
Rio Grande	10	10	21	26	34	33	43	48	52	56	58
Upper Colorado	6	6	7	7	58	56	74	83	89	95	98
Lower Colorado	10	10	24	36	37	36	47	53	57	61	63
Great Basin	16	27	38	29	36	35	46	51	55	59	61
Pacific Northwest	69	101	249	254	262	254	333	373	403	429	444
California	207	90	129	129	139	135	177	198	214	227	235
Alaska	6	8	6	9	11	11	14	16	17	18	19
Hawaii	8	0	0	0	4	4	5	6	6	7	7
Caribbean	11	5	3	20	8	8	10	11	12	13	14
Total Withdrawals	2005	2309	2609	2798	3442	3334	4380	4900	5300	5630	5830

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.6.—Freshwater withdrawals (million gallons per day) for livestock watering use in the United States from 1960 to 1985, by water resource region, with projections of demand to 2040

Water resource region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
New England	7	6	7	4	4	10	6	7	7	7	8
Mid-Atlantic	38	37	46	68	79	196	83	88	93	96	98
South Atlantic-Gulf	63	79	110	150	130	322	167	179	188	195	199
Great Lakes	64	57	62	60	64	159	80	85	90	93	95
Ohio	58	54	58	78	63	156	85	91	96	99	101
Tennessee	10	16	11	9	12	30	14	15	15	16	16
Upper Mississippi	200	260	200	200	220	546	266	284	299	310	316
Lower Mississippi	18	22	22	25	17	42	27	29	31	32	33
Souris-Red-Rainy	11	14	12	13	10	25	15	16	17	17	18
Missouri Basin	182	210	270	300	270	670	360	385	405	420	428
Arkansas-White-Red	56	60	66	86	85	211	102	109	114	118	121
Texas-Gulf	10	53	71	85	78	193	100	107	113	117	119
Rio Grande	8	38	17	18	26	64	26	28	29	30	31
Upper Colorado	1	2	6	6	2	5	6	6	7	7	7
Lower Colorado	9	16	18	32	12	30	27	28	30	31	32
Great Basin	10	23	35	38	34	84	46	49	52	53	54
Pacific Northwest	21	24	18	28	21	52	29	31	32	33	34
California	57	34	38	42	36	89	50	53	56	58	59
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	1	1	1	6	5	12	5	5	6	6	6
Caribbean	1	1	1	1	15	37	7	8	8	8	9
Total Groundwater	825	1007	1069	1249	1183	2934	1501	1603	1688	1749	1783
Surface Water											
New England	6	6	5	5	5	11	7	7	8	8	8
Mid-Atlantic	26	23	33	27	32	69	41	44	46	48	49
South Atlantic-Gulf	67	68	51	96	110	239	114	122	129	134	136
Great Lakes	28	22	24	25	20	43	31	33	35	36	37
Ohio	69	80	84	110	90	195	126	135	142	148	151
Tennessee	28	21	20	28	29	63	34	36	39	40	41
Upper Mississippi	91	56	60	63	51	111	77	82	87	90	92
Lower Mississippi	23	23	33	23	25	54	36	38	41	42	43
Souris-Red-Rainy	10	6	2	3	4	9	4	4	5	5	5
Missouri Basin	137	160	170	180	120	261	208	223	235	244	249
Arkansas-White-Red	86	93	120	140	150	326	182	194	205	213	217
Texas-Gulf	8	37	42	51	120	261	94	101	107	111	113
Rio Grande	6	31	20	20	6	13	20	22	23	24	24
Upper Colorado	8	9	12	9	91	198	50	53	56	58	59
Lower Colorado	3	3	10	17	5	11	14	15	16	17	17
Great Basin	11	6	6	10	12	26	12	13	14	15	15
Pacific Northwest	38	35	34	25	34	74	41	44	47	48	49
California	25	50	54	58	50	109	72	77	81	84	86
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	2	3	6	0	0	0	3	3	3	3	3
Caribbean	3	5	8	8	15	33	14	15	16	16	16
Total Surface Water	675	737	794	898	969	2104	1179	1261	1332	1383	1411
Total Withdrawals											
New England	13	12	12	9	9	21	13	14	15	15	16
Mid-Atlantic	64	60	79	95	111	260	124	132	140	145	148
South Atlantic-Gulf	130	147	161	246	240	562	282	301	317	329	335
Great Lakes	92	79	86	85	84	197	111	119	125	130	132
Ohio	127	134	142	188	153	358	210	224	237	245	250
Tennessee	38	37	31	37	41	96	47	51	53	55	57
Upper Mississippi	291	316	260	263	271	634	346	369	389	403	412
Lower Mississippi	41	45	55	48	42	98	63	67	71	74	75
Souris-Red-Rainy	21	20	14	16	14	33	19	20	22	22	23
Missouri Basin	319	370	440	480	390	913	570	609	642	666	679
Arkansas-White-Red	142	153	186	226	235	550	282	301	317	329	335
Texas-Gulf	18	90	113	136	198	463	195	208	219	227	232
Rio Grande	14	69	37	38	32	75	47	50	52	54	55
Upper Colorado	8	11	18	15	93	218	55	59	62	64	65
Lower Colorado	14	19	28	49	17	40	41	44	46	48	49
Great Basin	21	29	41	48	46	108	59	63	66	69	70
Pacific Northwest	59	59	52	53	55	129	70	74	78	81	83
California	82	84	92	100	86	201	121	129	136	141	144
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	3	4	7	6	5	12	8	8	9	9	9
Caribbean	4	6	9	9	30	70	21	22	24	24	25
Total Withdrawals	1501	1744	1863	2147	2152	5038	2683	2864	3020	3131	3195

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.7.—Freshwater withdrawals (million gallons per day) for thermoelectric steam cooling use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	3	1	1	2	2	1	1	1	1	1	1
Rocky Mountain	26	79	341	347	89	65	72	71	71	70	69
Southwestern	23	23	49	52	51	43	48	47	47	46	46
Intermountain	0	1	7	14	12	17	19	19	19	19	18
Pacific Southwest	303	330	383	521	1020	95	106	104	103	102	102
Pacific Northwest	0	0	0	0	0	1	1	1	1	1	1
Southern	530	618	167	172	208	201	223	220	217	215	214
Eastern	36	62	486	300	208	206	229	226	223	221	220
Alaskan	0	1	1	2	8	4	5	5	5	5	5
Total Groundwater	920	1115	1435	1410	1598	633	703	694	686	679	676
Surface Water											
Northern	65	136	413	780	1101	958	1153	1284	1414	1544	1675
Rocky Mountain	1526	984	1095	1119	2842	2873	3457	3848	4239	4630	5020
Southwestern	51	16	22	132	103	69	83	92	102	111	121
Intermountain	128	198	175	136	192	74	89	99	109	119	129
Pacific Southwest	152	697	1254	1131	1110	416	500	557	614	670	727
Pacific Northwest	3698	5	26	29	23	439	528	588	648	707	767
Southern	22571	27311	39400	48258	58076	49796	59926	66700	73475	80249	87021
Eastern	44849	61154	75865	78019	83295	75592	90970	101254	111538	121821	132101
Alaskan	86	1	68	18	22	26	31	35	38	42	45
Total Surface Water	73125	90503	118319	129622	146764	130243	156738	174457	192176	209893	227606
Total Withdrawals											
Northern	68	137	414	781	1103	959	0	1284	1413	1543	1673
Rocky Mountain	1552	1063	1437	1465	2931	2938	3534	3932	4329	4727	5124
Southwestern	74	39	71	184	154	112	135	150	165	180	195
Intermountain	128	199	182	150	204	91	110	122	135	147	159
Pacific Southwest	455	1027	1639	1651	2131	511	614	684	753	822	891
Pacific Northwest	3698	5	26	29	23	440	529	588	648	707	767
Southern	23101	27929	39565	48432	58284	49996	60145	66910	73676	80441	87207
Eastern	44883	61217	76349	78321	83502	75798	91184	101441	111698	121955	132212
Alaskan	86	2	69	20	30	30	36	41	45	49	53
Total Withdrawals	74045	91618	119754	131032	148362	130876	157441	175151	192862	210572	228282

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

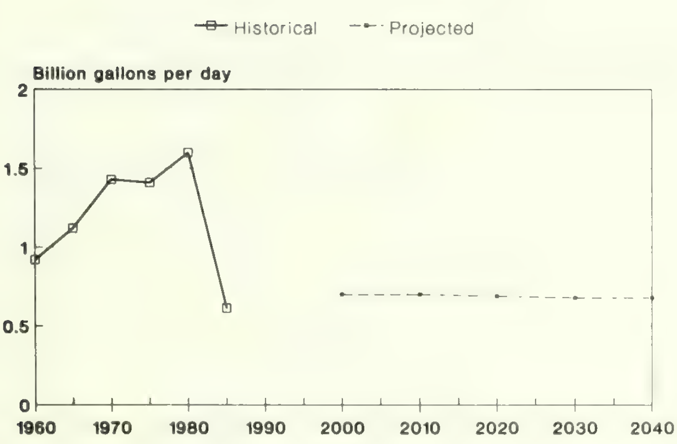

Figure A.3.—Thermoelectric steam cooling, fresh groundwater withdrawals.

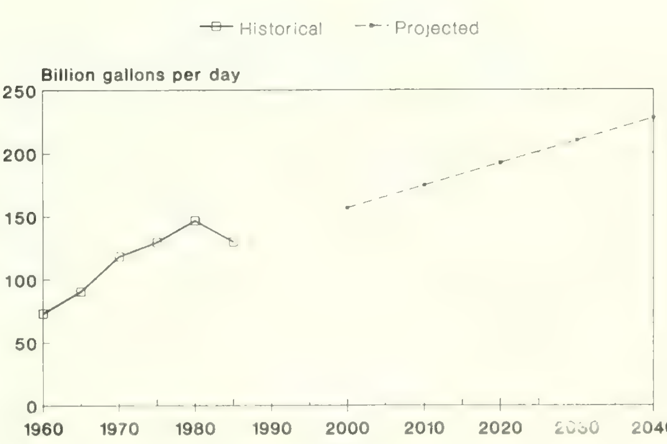

Figure A.4.—Thermoelectric steam cooling, fresh surface water withdrawals.

Table A.8.—Freshwater withdrawals (million gallons per day) for irrigation use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	541	626	551	929	1085	878	867	910	950	977	1001
Rocky Mountain	4077	5170	7534	12564	15037	12127	11972	12569	13118	13496	13823
Southwestern	3910	5100	5100	5500	5300	3670	3623	3804	3970	4084	4183
Intermountain	2442	3058	2469	3802	4341	3783	3735	3921	4092	4210	4312
Pacific Southwest	8880	11590	16550	17430	18460	11436	11290	11853	12371	12727	13036
Pacific Northwest	660	740	980	1150	1110	1100	1086	1140	1190	1224	1254
Southern	9819	15429	12054	15300	14759	12645	12484	13107	13679	14073	14414
Eastern	127	280	296	429	862	857	846	888	927	953	977
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Groundwater	30403	41572	45251	57074	61153	56292	55575	58347	60894	62649	64167
Surface Water											
Northern	6977	9314	10634	13771	12864	12128	12250	13143	14017	14736	15424
Rocky Mountain	11521	15999	17695	14652	17969	17310	17485	18759	20007	21033	22015
Southwestern	2620	3500	3900	4400	5400	4670	4717	5061	5398	5674	5939
Intermountain	11823	15653	16967	16231	15551	20364	20570	22069	23537	24745	25900
Pacific Southwest	9940	14580	17680	18520	19450	21070	21283	22834	24353	25602	26797
Pacific Northwest	7900	9300	9500	10400	11100	9550	9647	10349	11038	11604	12146
Southern	2706	5909	4956	5884	7034	6174	6236	6691	7136	7502	7852
Eastern	110	140	217	256	435	430	434	466	497	522	546
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Surface Water	54069	74360	81686	85012	90456	85767	86635	92947	99129	104215	109080
Wastewater											
Northern	0	0	0	1	3	0	1	1	1	1	1
Rocky Mountain	39	0	86	80	2	5	23	20	18	16	14
Southwestern	0	78	22	54	3	29	23	20	18	16	14
Intermountain	48	52	59	9	13	17	10	9	8	7	6
Pacific Southwest	430	400	177	160	150	253	149	132	116	102	90
Pacific Northwest	0	3	3	4	4	5	3	3	3	2	2
Southern	34	0	15	53	70	119	64	57	50	44	39
Eastern	10	1	0	0	30	26	15	13	11	10	9
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	562	535	366	365	279	453	290	257	225	199	176
Total Withdrawals											
Northern	7518	9940	11186	14701	13952	13006	13005	13831	14624	15246	15827
Rocky Mountain	15637	21169	25316	27295	33008	29441	29439	31309	33105	34513	35827
Southwestern	6530	8678	9022	9954	10703	8369	8368	8900	9411	9811	10184
Intermountain	14313	18763	19495	20041	19905	24164	24162	25696	27171	28327	29405
Pacific Southwest	19250	26570	34407	36110	38060	32759	32757	34837	36836	38403	39865
Pacific Northwest	8560	10043	10483	11554	12214	10655	10654	11330	11981	12490	12966
Southern	12559	21338	17025	21237	21863	18938	18936	20139	21294	22200	23045
Eastern	247	421	513	685	1327	1312	1312	1395	1475	1538	1597
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Withdrawals	84933	116467	127303	142451	151888	142512	142500	151551	160248	167063	173423

Source: Data for 1960 through 1980 from USGS Circulars. In addition to the irrigation of crops, this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional nonagricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.9.—Freshwater withdrawals (million gallons per day) for municipal central supplies in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	62	66	75	94	113	135	182	218	256	286	305
Rocky Mountain	350	353	419	471	466	550	740	889	1040	1165	1242
Southwestern	184	261	322	443	488	583	784	941	1102	1234	1316
Intermountain	221	256	313	345	593	538	723	868	1016	1137	1213
Pacific Southwest	1276	1995	1730	1884	2072	4202	5649	6784	7942	8891	9482
Pacific Northwest	371	311	359	337	365	422	567	681	798	893	952
Southern	1796	2185	2626	3182	3811	4471	6011	7219	8451	9460	10089
Eastern	2053	2657	3652	3989	3786	3991	5366	6443	7543	8444	9006
Alaskan	8	12	24	35	23	41	55	66	77	87	93
Total Ground Water	6321	8096	9520	10781	11717	14933	20077	24110	28225	31597	33697
Surface Water											
Northern	115	95	116	121	132	143	200	227	253	273	286
Rocky Mountain	418	532	500	637	813	911	1275	1447	1613	1743	1822
Southwestern	66	71	136	147	281	261	365	414	462	499	522
Intermountain	183	193	200	265	533	374	523	594	662	716	748
Pacific Southwest	1410	2068	1810	2018	2216	1461	2045	2320	2586	2795	2922
Pacific Northwest	789	775	769	662	670	948	1327	1505	1678	1814	1896
Southern	2531	2801	3630	4258	6986	6322	8850	10039	11191	12096	12645
Eastern	8640	9187	10716	10683	10658	11310	15831	17960	20020	21639	22621
Alaskan	15	20	35	46	30	35	49	56	62	67	70
Total Surface Water	14166	15743	17912	18838	22319	21765	30466	34562	38527	41643	43532
Total Withdrawals											
Northern	177	160	191	215	244	278	382	442	501	548	584
Rocky Mountain	768	885	919	1108	1279	1462	2007	2322	2633	2880	3071
Southwestern	250	330	457	590	770	844	1159	1341	1520	1663	1773
Intermountain	403	447	512	609	1127	912	1252	1448	1642	1796	1915
Pacific Southwest	2684	4054	3536	3900	4290	5663	7776	8996	10200	11159	11897
Pacific Northwest	1160	1087	1128	1000	1035	1370	1881	2176	2468	2700	2878
Southern	4326	4978	6253	7439	10798	10794	14821	17147	19441	21269	22676
Eastern	10696	11867	14378	14677	14439	15301	21010	24308	27559	30151	32146
Alaskan	23	32	59	81	53	76	104	121	137	150	160
Total Withdrawals	20487	23839	27432	29619	34036	36699	50392	58301	66100	72316	77100

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

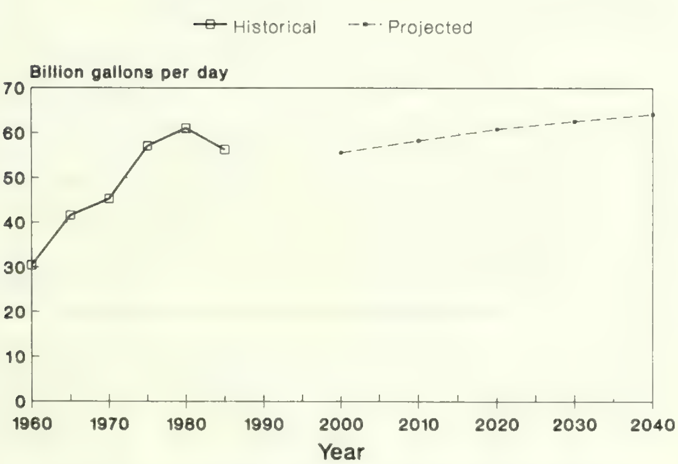

Figure A.5.—Irrigation, fresh groundwater withdrawals.

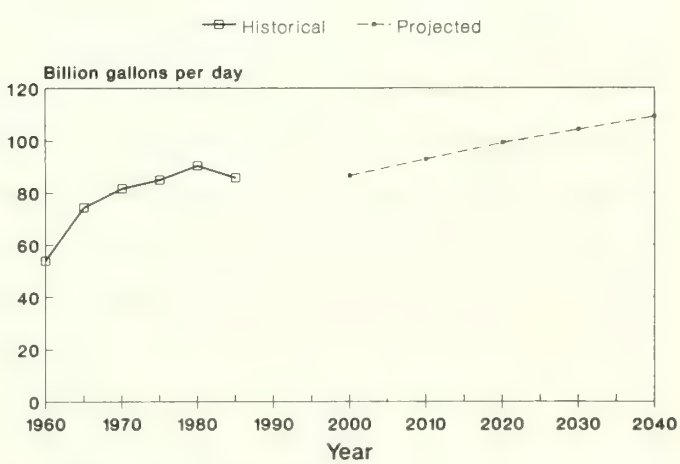

Figure A.6.—Irrigation, fresh surface water withdrawals.

Table A.10.—Freshwater withdrawals (million gallons per day) for industrial self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	57	48	114	446	497	76	91	104	120	136	152
Rocky Mountain	230	210	342	385	332	156	186	215	246	279	313
Southwestern	79	171	222	254	147	68	82	94	108	122	137
Intermountain	175	155	373	1625	1804	187	223	257	295	334	375
Pacific Southwest	415	542	569	485	430	420	502	579	663	751	844
Pacific Northwest	211	298	260	209	230	159	190	219	251	284	320
Southern	2747	2621	3268	3716	3646	1872	2236	2578	2954	3346	3761
Eastern	2124	2743	2849	2563	3248	1704	2036	2348	2690	3048	3425
Alaskan	12	7	8	0	6	8	10	11	13	14	16
Total Groundwater	6050	6794	8005	9683	10340	4650	5555	6405	7339	8314	9345
Surface Water											
Northern	193	112	149	120	108	40	44	48	51	55	58
Rocky Mountain	221	181	187	198	827	146	160	174	188	201	214
Southwestern	20	26	38	25	20	8	9	10	10	11	12
Intermountain	233	212	260	277	564	38	42	46	49	53	56
Pacific Southwest	76	102	128	136	81	121	132	144	155	166	177
Pacific Northwest	3234	1242	998	1130	1245	674	737	803	865	926	985
Southern	6473	6454	9089	9262	10524	7711	8437	9183	9897	10595	11271
Eastern	16641	21241	20202	17360	15187	10965	11996	13058	14073	15066	16027
Alaskan	71	94	100	90	120	106	116	126	136	146	155
Total Surface Water	27161	29664	31152	28598	28675	19810	21673	23591	25425	27218	28955
Wastewater											
Northern	0	0	0	0	0	0	0	0	0	0	0
Rocky Mountain	0	0	0	0	0	0	0	0	0	0	0
Southwestern	0	0	0	0	2	5	4	5	6	6	7
Intermountain	0	1	0	8	11	0	12	14	16	18	20
Pacific Southwest	1	1	13	2	19	3	15	17	20	22	25
Pacific Northwest	0	0	0	0	0	1	0	0	0	1	1
Southern	0	7	6	9	0	55	39	46	53	60	66
Eastern	70	131	130	150	160	81	238	280	322	364	406
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Wastewater	71	140	149	169	192	144	308	362	416	471	525
Total Withdrawals											
Northern	250	160	264	567	605	116	129	142	155	168	181
Rocky Mountain	454	391	528	584	1161	302	336	370	405	439	473
Southwestern	101	197	260	280	167	76	85	94	102	111	120
Intermountain	411	366	634	1907	2366	225	251	276	302	327	353
Pacific Southwest	498	644	697	623	510	541	602	663	724	786	847
Pacific Northwest	3437	1540	1258	1339	1480	833	927	1022	1116	1210	1304
Southern	9247	9075	12358	12979	14203	9583	10667	11752	12836	13921	15005
Eastern	18745	23985	23052	19912	18488	12670	14103	15537	16971	18405	19838
Alaskan	83	101	108	90	126	114	127	140	153	166	179
Total Withdrawals	33225	36458	39157	38281	39105	24460	27228	29996	32764	35532	38300

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.11.—Freshwater withdrawals (million gallons per day) for domestic self-supplied use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	23	27	32	44	82	48	61	68	74	79	81
Rocky Mountain	71	80	97	110	168	105	134	148	162	172	178
Southwestern	37	10	38	56	64	34	81	90	98	104	108
Intermountain	24	46	47	54	73	80	101	112	122	130	134
Pacific Southwest	202	79	120	120	133	131	166	184	201	213	221
Pacific Northwest	18	74	203	189	169	168	213	236	258	274	283
Southern	542	888	869	928	1238	1115	1416	1568	1709	1815	1877
Eastern	915	984	1083	1160	1327	1531	1945	2153	2347	2492	2578
Alaskan	5	6	4	6	11	9	11	13	14	15	15
Total Groundwater	1838	2193	2493	2666	3265	3251	4131	4573	4985	5293	5475
Surface Water											
Northern	1	0	2	1	1	0	0	0	0	0	0
Rocky Mountain	4	9	7	7	68	3	5	5	5	5	5
Southwestern	3	2	1	1	1	1	2	2	2	2	2
Intermountain	3	2	2	4	6	2	3	3	3	3	3
Pacific Southwest	22	9	9	9	10	30	47	47	47	47	47
Pacific Northwest	30	5	26	30	30	10	15	15	15	15	15
Southern	22	25	17	29	14	16	25	25	25	25	25
Eastern	77	63	50	47	47	20	31	31	31	31	31
Alaskan	1	2	2	3	0	1	1	1	1	1	1
Total Surface Water	163	116	116	132	177	83	129	129	129	129	129
Total Withdrawals											
Northern	25	27	34	45	83	48	68	76	83	89	92
Rocky Mountain	76	89	104	117	235	109	152	170	187	200	207
Southwestern	41	12	39	57	65	65	91	102	113	120	125
Intermountain	27	48	49	58	79	82	115	128	141	150	156
Pacific Southwest	224	87	129	129	143	161	225	252	277	296	307
Pacific Northwest	46	78	229	219	199	178	248	278	306	326	338
Southern	567	912	887	958	1253	1131	1582	1772	1946	2077	2154
Eastern	994	1047	1133	1207	1374	1550	2169	2429	2668	2847	2953
Alaskan	6	8	6	9	11	10	14	15	17	18	18
Total Withdrawals	2005	2309	2609	2798	3442	3334	4664	5224	5737	6123	6351

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

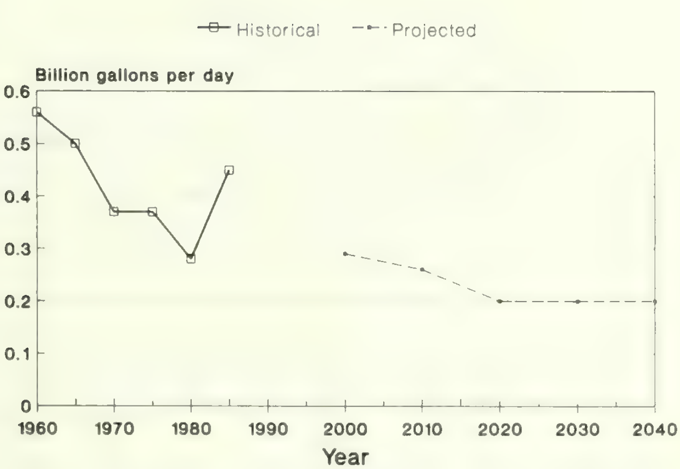

Figure A.7.—Irrigation, wastewater withdrawals.

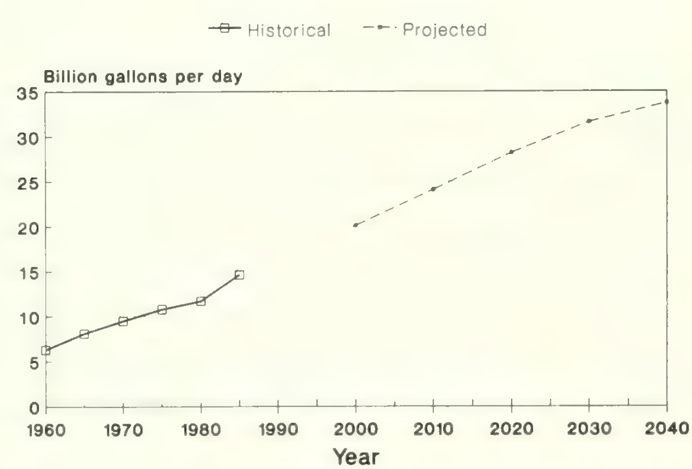

Figure A.8.—Municipal supplies, fresh groundwater withdrawals.

Table A.12.—Freshwater withdrawals (million gallons per day) for livestock watering use in the United States for 1960 to 1985, by Forest Service Region, with projections of demand to 2040

Forest Service region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Groundwater											
Northern	17	35	36	42	36	258	132	141	149	154	157
Rocky Mountain	136	167	208	236	225	179	92	98	103	107	109
Southwestern	19	42	32	43	20	36	18	20	21	21	22
Intermountain	16	38	45	55	43	851	436	465	490	507	517
Pacific Southwest	58	35	39	48	42	42	21	23	24	25	25
Pacific Northwest	11	13	7	7	11	25	13	14	14	15	15
Southern	180	220	277	346	326	992	507	542	571	591	603
Eastern	388	456	426	472	479	541	277	296	311	322	329
Alaskan	0	0	0	0	0	10	5	5	6	6	6
Total Groundwater	825	1007	1069	1249	1183	2934	1501	1603	1688	1749	1783
Surface Water											
Northern	49	40	27	28	26	45	31	33	35	36	37
Rocky Mountain	72	91	119	99	173	126	211	225	238	247	252
Southwestern	9	37	40	44	12	75	14	15	16	17	17
Intermountain	21	17	18	16	29	30	36	38	40	42	43
Pacific Southwest	26	51	59	59	51	162	61	66	69	72	74
Pacific Northwest	26	24	21	21	21	813	25	27	29	30	30
Southern	243	263	281	359	475	542	577	618	652	677	691
Eastern	230	215	228	272	183	165	223	239	252	262	267
Alaskan	0	0	0	0	0	146	0	0	0	0	0
Total Surface Water	675	737	794	898	969	2104	1179	1261	1332	1383	1411
Total Withdrawals											
Northern	66	75	63	70	61	303	162	173	182	189	192
Rocky Mountain	209	258	328	335	399	305	162	173	183	190	194
Southwestern	27	79	72	87	32	111	59	63	67	69	70
Intermountain	37	56	63	70	72	881	469	501	528	548	559
Pacific Southwest	84	86	98	108	93	204	108	116	122	127	129
Pacific Northwest	37	37	28	28	32	838	446	476	502	521	531
Southern	421	485	558	705	803	1534	817	872	920	953	973
Eastern	620	670	654	744	660	706	376	401	423	439	448
Alaskan	0	0	0	0	0	156	83	89	93	97	99
Total Withdrawals	1501	1744	1863	2147	2152	5038	2683	2864	3020	3131	3195

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

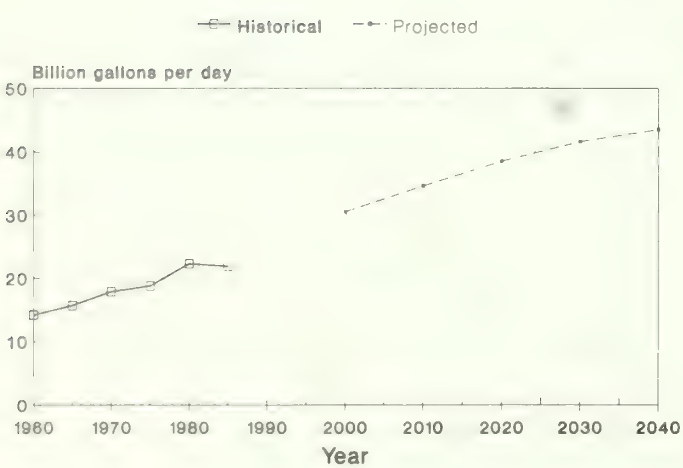

Figure A.9.—Municipal supplies, fresh surface water withdrawals.

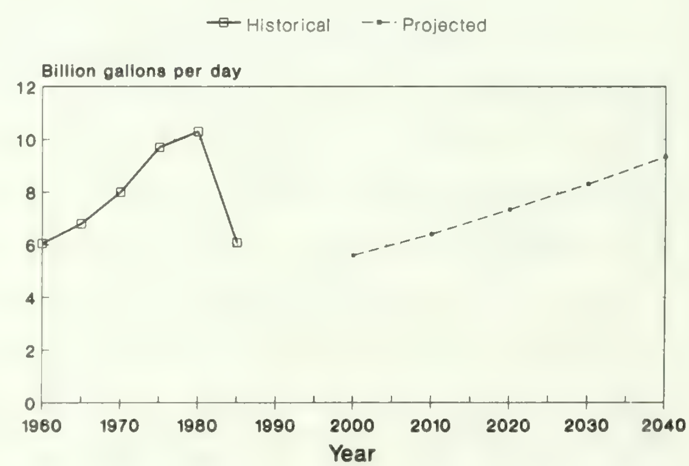

Figure A.10.—Industrial self-supplied water, fresh groundwater withdrawals.

Table A.13.—Freshwater consumption (million gallons per day) for thermoelectric steam cooling use in the United States for 1960 to 1985 by Water Resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	1	3	3	96	21	31	50	60	68	78	91
Mid-Atlantic	15	27	35	140	260	389	623	747	843	969	1122
South Atlantic-Gulf	7	11	120	210	270	404	647	775	875	1006	1165
Great Lakes	12	11	14	52	93	139	223	267	301	346	401
Ohio	33	17	50	280	520	778	1246	1493	1685	1937	2245
Tennessee	0	8	64	59	20	30	48	57	65	75	86
Upper Mississippi	4	27	23	96	290	434	695	833	940	1080	1252
Lower Mississippi	19	20	190	290	400	598	959	1149	1296	1490	1727
Souris-Red-Rainy	2	1	1	1	1	1	2	3	3	4	4
Missouri Basin	12	31	34	68	350	523	839	1005	1134	1304	1511
Arkansas-White-Red	29	54	82	95	410	613	982	1177	1329	1527	1770
Texas-Gulf	52	140	100	380	360	538	863	1034	1167	1341	1554
Rio Grande	4	11	17	20	11	16	26	32	36	41	47
Upper Colorado	8	18	22	60	130	194	312	373	421	484	561
Lower Colorado	7	15	36	47	49	73	117	141	159	183	212
Great Basin	2	2	6	6	6	9	14	17	19	22	26
Pacific Northwest	0	0	0	9	2	3	5	6	6	7	9
California	17	18	24	32	41	61	98	118	133	153	177
Alaska	0	0	0	1	0	0	0	0	0	0	0
Hawaii	0	0	0	0	0	0	0	0	0	0	0
Caribbean	0	1	0	5	6	9	14	17	19	22	26
U.S. Total	224	415	821	1947	3240	4846	7764	9303	10499	12070	13985
Forest Service region											
Northern	2	2	1	20	26	41	66	79	89	102	118
Rocky Mountain	22	46	53	77	197	113	181	216	244	281	325
Southwestern	20	31	59	74	106	96	154	184	208	239	277
Intermountain	4	4	13	36	39	51	82	98	111	128	148
Pacific Southwest	17	18	24	32	41	26	41	50	56	65	75
Pacific Northwest	10	0	0	7	1	25	40	48	54	62	72
Southern	96	228	568	1061	1536	1085	1739	2083	2351	2703	3132
Eastern	53	87	106	630	1294	3406	5457	6539	7379	8483	9829
Alaskan	0	0	0	1	0	3	5	6	7	8	9
Total Consumption	224	415	821	1947	3240	4846	7764	9303	10499	12070	13985

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

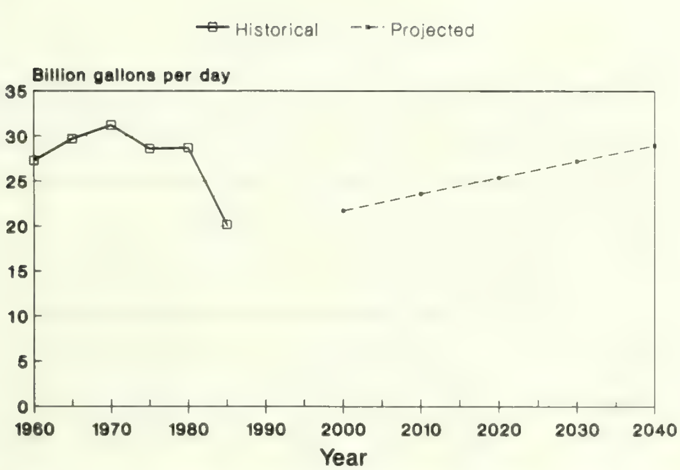

Figure A.11.—Industrial self-supplied water, fresh surface water withdrawals.

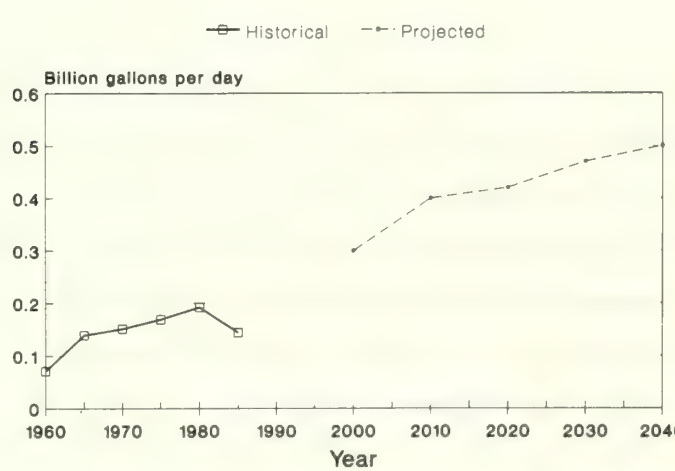

Figure A.12.—Industrial self-supplied water, wastewater withdrawals.

Table A.14.—Freshwater consumption (million gallons per day) for irrigation use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	7	26	64	57	52	46	55	57	60	61	63
Mid-Atlantic	82	122	120	200	240	212	253	264	275	284	292
South Atlantic-Gulf	797	1400	1500	1500	2300	2028	2421	2531	2637	2720	2797
Great Lakes	45	64	87	94	330	291	347	363	378	390	401
Ohio	12	24	35	32	150	132	158	165	172	177	182
Tennessee	14	8	7	7	7	6	7	8	8	8	9
Upper Mississippi	44	77	95	140	370	326	389	407	424	438	450
Lower Mississippi	660	1200	2200	4000	4800	4232	5053	5283	5504	5677	5838
Souris-Red-Rainy	9	17	12	41	60	53	63	66	69	71	73
Missouri Basin	6946	9800	12000	14000	15000	13225	15790	16509	17199	17740	18245
Arkansas-White-Red	3390	7700	6000	8000	8200	7229	8632	9025	9402	9698	9974
Texas-Gulf	4798	5500	4900	6500	4900	4320	5158	5393	5618	5795	5960
Rio Grande	3402	3900	3000	3200	2100	1851	2211	2311	2408	2484	2554
Upper Colorado	3505	3200	4000	1500	2000	1763	2105	2201	2293	2365	2433
Lower Colorado	3395	3100	4700	5700	4300	3791	4527	4732	4930	5085	5230
Great Basin	3300	3000	2900	3400	3500	3086	3684	3852	4013	4139	4257
Pacific Northwest	8000	10000	10000	9900	11000	9698	11580	12106	12612	13009	13379
California	13000	16000	21000	21000	23000	20278	24212	25313	26371	27201	27975
Alaska	0	0	1	0	0	0	0	0	0	0	0
Hawaii	370	530	750	500	610	538	642	671	699	721	742
Caribbean	250	230	98	150	200	176	211	220	229	237	243
U.S. Total	52026	65898	73469	79921	83119	73282	87498	91479	95303	98301	101098
Forest Service region											
Northern	3471	5750	6663	3901	4109	3041	3631	3796	3955	4079	4196
Rocky Mountain	9193	12029	14586	16513	17656	15997	19101	19970	20804	21459	22069
Southwestern	4224	4436	5882	6812	5706	4439	5301	5542	5773	5955	6124
Intermcuntain	7186	8276	7624	7773	8770	8211	9804	10250	10679	11015	11328
Pacific Southwest	14453	15659	21044	21537	23636	18818	22469	23491	24473	25243	25961
Pacific Northwest	4124	4436	4564	5209	5606	6889	8225	8600	8959	9241	9504
Southern	9143	14913	12646	17564	16356	14699	17550	18349	19116	19717	20278
Eastern	233	398	460	613	1278	1187	1417	1481	1543	1592	1637
Alaskan	0	0	1	0	0	0	0	0	0	0	0
Total Consumption	52026	65898	73469	79921	83119	73282	87498	91479	95303	98301	101098

Source: Data for 1960 through 1980 from USGS Circulars. In addition to the irrigation of crops this data also includes irrigation of recreational facilities (e.g. golf courses and ski slopes) and other uses (e.g. landscape plantings) if water source is self-supplied. Data for 1985 from the Soil Conservation Service, modified by additional nonagricultural irrigation use. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

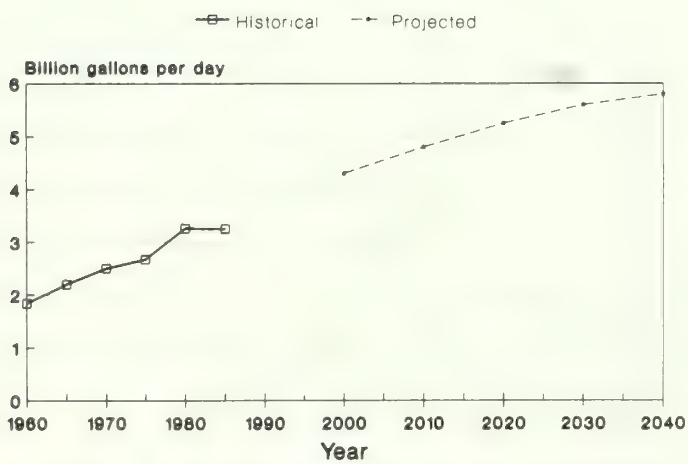

Figure A.13.—Domestic self-supplied water, fresh groundwater withdrawals.

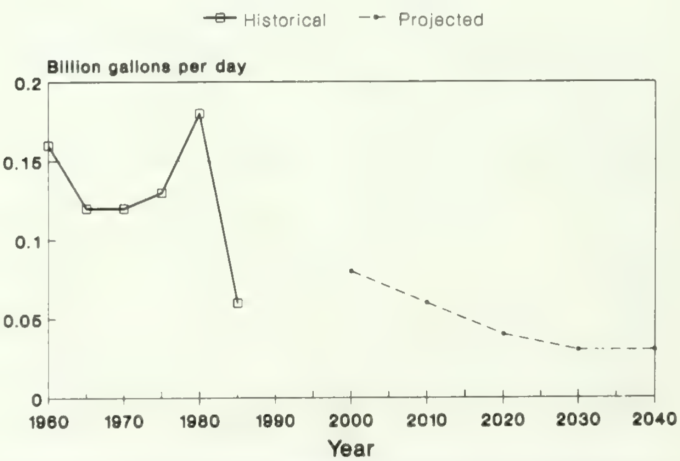

Figure A.14.—Domestic self-supplied water, fresh surface water withdrawals.

Table A.15.—Freshwater consumption (million gallons per day) for municipal central supplies in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	150	160	190	180	150	130	217	239	258	272	280
Mid-Atlantic	452	681	750	760	710	615	1027	1132	1223	1289	1326
South Atlantic-Gulf	300	360	590	930	780	676	1128	1244	1344	1416	1457
Great Lakes	400	520	500	410	310	269	448	494	534	563	579
Ohio	190	230	270	240	240	208	347	383	414	436	448
Tennessee	60	46	36	40	44	38	64	70	76	80	82
Upper Mississippi	130	160	190	170	180	156	260	287	310	327	336
Lower Mississippi	110	200	240	310	400	347	578	638	689	726	747
Souris-Red-Rainy	9	11	19	20	22	19	32	35	38	40	41
Missouri Basin	212	240	250	290	360	312	521	574	620	653	672
Arkansas-White-Red	196	260	250	330	310	269	448	494	534	563	579
Texas-Gulf	396	350	380	560	550	477	795	877	948	998	1027
Rio Grande	124	110	150	190	140	121	202	223	241	254	261
Upper Colorado	10	14	19	26	41	36	59	65	71	74	77
Lower Colorado	110	150	190	240	390	338	564	622	672	708	728
Great Basin	67	69	140	140	310	269	448	494	534	563	579
Pacific Northwest	150	210	260	230	290	251	419	463	500	526	542
California	370	1300	1400	1500	1700	1473	2458	2711	2929	3086	3175
Alaska	0	7	11	4	33	29	48	53	57	60	62
Hawaii	25	38	46	55	60	52	87	96	103	109	112
Caribbean	11	21	43	42	75	65	108	120	129	136	140
U.S. Total	3472	5137	5924	6667	7095	6149	10259	11316	12226	12878	13250
Forest Service region											
Northern	74	61	91	87	99	86	143	158	171	180	185
Rocky Mountain	191	241	235	275	348	302	503	555	600	632	650
Southwestern	123	161	227	283	438	380	634	699	755	795	818
Intermountain	108	121	202	212	417	362	603	665	719	757	779
Pacific Southwest	395	1324	1455	1557	1757	1522	2540	2802	3027	3188	3280
Pacific Northwest	113	186	209	176	217	188	313	345	373	393	404
Southern	1139	1301	1612	2323	2172	1882	3140	3464	3742	3942	4056
Eastern	1329	1735	1881	1749	1615	1399	2335	2575	2783	2931	3016
Alaskan	0	7	11	4	33	29	48	53	57	60	62
Total Consumption	3472	5137	5924	6667	7095	6149	10259	11316	12226	12878	13250

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

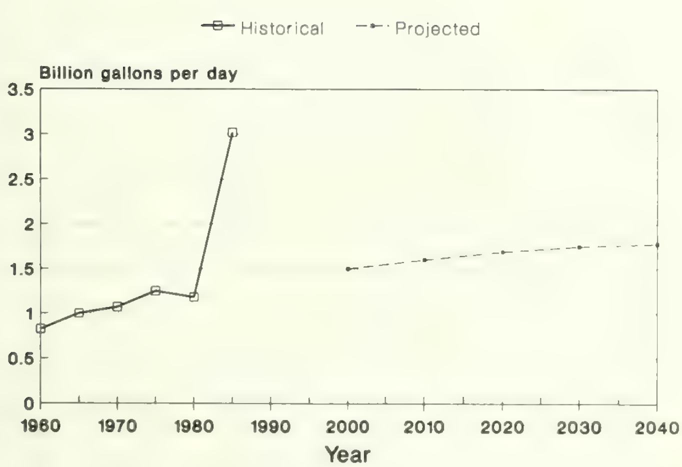

Figure A.15.—Livestock watering, fresh groundwater withdrawals.

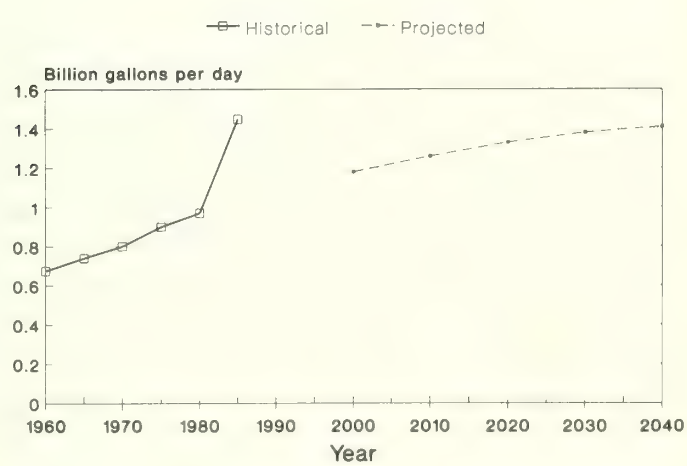

Figure A.16.—Livestock watering, fresh surface water withdrawals.

Table A.16.—Freshwater consumption (million gallons per day) for industrial self-supplied use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	84	79	96	64	66	72	88	100	112	123	135
Mid-Atlantic	460	470	330	340	280	307	375	424	473	523	573
South Atlantic-Gulf	430	260	540	540	1100	1204	1473	1665	1859	2054	2249
Great Lakes	280	360	450	370	370	405	495	560	625	691	757
Ohio	310	410	260	360	420	460	562	636	710	784	859
Tennessee	240	170	72	120	220	241	295	333	372	411	450
Upper Mississippi	36	58	75	98	170	186	228	257	287	317	348
Lower Mississippi	380	450	780	810	740	810	991	1120	1251	1382	1513
Souris-Red-Rainy	7	2	6	5	6	7	8	9	10	11	12
Missouri Basin	55	71	65	52	77	84	103	117	130	144	157
Arkansas-White-Red	185	330	210	270	330	361	442	500	558	616	675
Texas-Gulf	239	350	580	290	350	383	469	530	592	653	716
Rio Grande	31	46	97	55	13	14	17	20	22	24	27
Upper Colorado	5	8	21	27	63	69	84	95	106	118	129
Lower Colorado	32	51	100	190	150	164	201	227	254	280	307
Great Basin	9	36	62	63	100	109	134	151	169	187	204
Pacific Northwest	91	83	150	310	350	383	469	530	592	653	716
California	80	110	170	180	190	208	254	288	321	355	389
Alaska	0	4	4	0	1	1	1	2	2	2	2
Hawaii	13	4	4	4	0	0	0	0	0	0	0
Caribbean	7	10	18	37	20	22	27	30	34	37	41
U.S. Total	2974	3362	4090	4185	5016	5492	6715	7594	8478	9365	10257
Forest Service region											
Northern	32	24	28	50	57	33	41	46	51	57	62
Rocky Mountain	54	71	113	119	165	172	211	238	266	294	322
Southwestern	28	92	137	221	125	159	194	220	245	271	297
Intermountain	43	61	100	211	278	47	57	65	72	80	87
Pacific Southwest	95	114	175	183	191	679	830	939	1048	1158	1268
Pacific Northwest	154	64	126	149	171	159	194	220	245	271	297
Southern	1524	1581	2220	2075	2781	1945	2378	2690	3003	3317	3633
Eastern	1045	1351	1187	1177	1247	2282	2790	3155	3523	3891	4262
Alaskan	0	4	4	0	1	16	19	22	24	27	29
Total Consumption	2974	3362	4090	4185	5016	5492	6715	7594	8478	9365	10257

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.17.—Freshwater consumption (million gallons per day) for domestic self-supplied use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	31	84	47	36	63	46	48	49	50	51	51
Mid-Atlantic	86	88	130	100	110	106	112	115	117	119	120
South Atlantic-Gulf	310	490	360	340	440	357	375	385	392	398	401
Great Lakes	96	100	78	61	74	67	70	72	73	74	75
Ohio	140	200	180	140	200	163	171	175	179	182	183
Tennessee	54	61	31	25	39	30	31	32	33	33	33
Upper Mississippi	73	100	130	48	190	115	121	124	127	128	130
Lower Mississippi	52	58	100	68	67	74	77	79	81	82	83
Souris-Red-Rainy	7	14	19	11	23	17	17	18	18	19	19
Missouri Basin	89	85	96	110	170	118	124	127	129	131	132
Arkansas-White-Red	70	96	84	97	120	94	99	102	104	105	106
Texas-Gulf	29	33	80	100	120	94	99	101	103	105	106
Rio Grande	6	7	13	17	18	15	16	16	17	17	17
Upper Colorado	2	2	3	3	17	7	8	8	8	8	8
Lower Colorado	6	5	17	27	27	22	23	24	24	25	25
Great Basin	8	15	13	6	14	10	11	11	11	12	12
Pacific Northwest	23	75	200	180	200	182	191	196	200	202	204
California	120	51	73	76	84	73	77	79	80	81	82
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	6	0	0	0	3	1	1	1	1	1	1
Caribbean	9	4	3	4	2	3	3	3	3	3	3
U.S. Total	1217	1568	1657	1449	1981	1592	1675	1716	1751	1776	1791
Forest Service region											
Northern	12	24	29	40	75	45	47	49	50	50	51
Rocky Mountain	68	80	88	97	152	106	111	114	116	118	119
Southwestern	31	8	24	37	39	31	33	34	35	35	35
Intermountain	9	23	19	14	27	19	20	20	21	21	21
Pacific Southwest	133	50	71	74	85	72	76	78	79	81	81
Pacific Northwest	18	67	190	169	168	165	173	178	181	184	185
Southern	519	798	721	661	842	696	732	750	766	777	783
Eastern	427	517	513	356	594	458	482	494	504	511	515
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Consumption	1217	1568	1657	1449	1981	1592	1675	1716	1751	1776	1791

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data.

Table A.18.—Freshwater consumption (million gallons per day) for livestock watering use in the United States for 1960 to 1985 by water resource region and Forest Service region, with projections of demand to 2040

Region	1960	1965	1970	1975	1980	1985	2000	2010	2020	2030	2040
Water resource region											
New England	13	11	12	9	9	11	11	12	12	12	13
Mid-Atlantic	58	51	65	76	86	103	105	110	116	119	121
South Atlantic-Gulf	127	140	150	240	240	287	292	308	323	333	338
Great Lakes	85	72	82	78	77	92	94	99	103	107	109
Ohio	130	130	140	170	140	168	170	180	188	194	197
Tennessee	38	36	30	32	40	48	49	51	54	55	56
Upper Mississippi	290	300	250	250	270	323	328	347	363	374	381
Lower Mississippi	41	44	55	47	41	49	50	53	55	57	58
Souris-Red-Rainy	21	19	15	16	14	17	17	18	19	19	20
Missouri Basin	301	360	410	440	380	455	462	488	511	527	536
Arkansas-White-Red	139	150	180	220	230	275	280	295	309	319	324
Texas-Gulf	16	89	110	140	190	227	231	244	255	263	268
Rio Grande	13	68	36	37	26	31	32	33	35	36	37
Upper Colorado	7	10	17	14	22	26	27	28	30	30	31
Lower Colorado	12	16	28	47	11	13	13	14	15	15	16
Great Basin	19	16	21	20	17	20	21	22	23	24	24
Pacific Northwest	55	55	47	47	49	59	60	63	66	68	69
California	66	45	50	54	47	56	57	60	63	65	66
Alaska	0	0	0	0	0	0	0	0	0	0	0
Hawaii	2	3	7	5	5	6	6	6	7	7	7
Caribbean	4	6	8	9	7	8	8	9	9	9	9
U.S. Total	1437	1621	1713	1951	1901	2276	2311	2442	2555	2635	2681
Forest Service region											
Northern	65	74	61	67	60	98	100	105	110	114	116
Rocky Mountain	196	251	304	307	314	271	275	291	304	314	319
Southwestern	22	78	71	86	18	59	60	63	66	68	69
Intermountain	32	36	39	38	38	96	98	103	108	112	114
Pacific Southwest	68	47	56	59	51	157	160	169	176	182	185
Pacific Northwest	35	35	26	25	29	50	51	54	56	58	59
Southern	416	472	540	680	769	911	925	977	1022	1054	1073
Eastern	603	628	614	689	623	633	643	680	711	733	746
Alaskan	0	0	0	0	0	0	0	0	0	0	0
Total Consumption	1437	1621	1713	1951	1901	2276	2311	2442	2555	2635	2681

Source: Data for 1960 through 1985 from USGS Circulars. Data for 2000 through 2040 are Forest Service estimates based upon trends in the historical data

APPENDIX B: DEMAND EQUATIONS

INTRODUCTION

Demand equations were estimated using the 1987 release of *BMDP for the Personal Computer*, which executes the same routines outlined by Dixon et al. (1985). The stepwise regression routine was used to explore possible independent variables (table 11) for each dependent variable and transformation. Further analyses were performed using multiple linear regression.

Several different curve forms were tested for fit against the data. The prior assumption was that a logarithmic curve form was the most appropriate, given the emphasis on recycling and conservation engendered by legislation of the early 1970s. Semilogarithmic ($Y = \ln a + b \ln X$) and double logarithmic ($\ln Y = \ln a + b \ln X$; shown below as $\exp[c + b \ln x]$ where $c = \ln a$) curve forms were explored in preference to linear forms. The *BMDP Data Manager for the Personal Computer* (Engelman et al. 1986) was used to perform the natural logarithm transformations of dependent and independent variables.

Unless otherwise specified, F statistics listed are for equations with a single explanatory variable and a time series of six data points (1960 to 1985 inclusive). The critical values for $F_{1,5}$ are 4.06, 6.61, and 16.3 for 10%, 5%, and 1%, respectively.

THERMOELECTRIC STEAM COOLING

EQUATIONS

Total freshwater withdrawals =
$\exp[7.6658 + 0.5656 \ln \text{kWh}]$
$R^2 = .93 \quad F = 51.6$

Groundwater withdrawals = No significant equations

Fresh surface water withdrawals =
$\exp[7.6241 + 0.5701 \ln \text{kWh}]$
$R^2 = .94 \quad F = 60.0$

Freshwater consumption =
$-10642 - 3.2887 \text{ kWh} + 182.446 \text{ civilian labor force}$
$R^2 = .98 \quad F = 91.2$

DISCUSSION

Because no significant equations emerged for groundwater withdrawals, demand for fresh groundwater withdrawals was estimated as the difference between total freshwater withdrawals and fresh surface water withdrawals. Saline surface water (oceans and estuaries) is an alternative source of water for thermoelectric steam cooling. Because those utilities using groundwater are usually located in arid areas far removed from coastal sites where saline surface sources are available, saline surface sources were ignored for purposes of estimating groundwater withdrawals.

Billion kWh of power generated was selected as the best independent variable for projecting steam cooling withdrawals and consumption. The double exponential form suggests that conservation and recycling will continue to grow, but at a decreasing rate. Billion kWh were projected based upon the GNP relationships identified by the U.S. Department of Energy and the GNP projections from the basic assumptions for this Assessment.

IRRIGATION

EQUATIONS

Total freshwater withdrawals =
$-227076 + 50465.68 \ln \text{kWh}$
$R^2 = .88 \quad F = 30.2$

Groundwater withdrawals =
$-94490 + 20168.35 \ln \text{kWh}$
$R^2 = .66 \quad F = 7.9$

Fresh surface water withdrawals =
$-133814 + 30414.04 \ln \text{kWh}$
$R^2 = .94 \quad F = 67.3$

Wastewater withdrawals =
$1736 - 186.71 \ln \text{kWh}$
$R^2 = 57.8 \quad F = 5.5$

Freshwater consumption =
$-84411 + 22194.83 \ln \text{kWh}$
$R^2 = .79 \quad F = 14.8$

DISCUSSION

The wastewater withdrawals equation has an F statistic that is significant at the 7% level. Because wastewater withdrawals represent only 0.2% of the total demand for irrigation water in 1985, this level of significance was judged acceptable for projecting irrigation withdrawals. No other form or independent variable gave better results.

Billion kWh was selected as the most relevant independent variable to explain irrigation withdrawals and consumption. Electricity is the primary energy source used to pump water from aquifers and surface sources and pressurize sprinkler water delivery systems.

MUNICIPAL SUPPLIES

EQUATIONS

Total freshwater withdrawals =
$\exp[-1.1803 + 2.138 \ln \text{population}]$
$R^2 = .987 \quad F = 235.4$

Groundwater withdrawals =

$$\exp[-5.1671 + 2.6840 \ln \text{population}]$$
$R^2 = .976 \quad F = 120.9$

Fresh surface water withdrawals =

$$\exp[-0.0643 + 1.8497 \ln \text{population}]$$
$R^2 = .971 \quad F = 98.9$

Freshwater consumption =

$$-76821 + 15504.6 \ln \text{population}$$
$R^2 = .95 \quad F = 72.8$

DISCUSSION

Population is the most relevant independent variable for explaining changes in municipal withdrawals and consumption. Municipal supplies also serve some commercial and industrial facilities but usage by these firms is largely for people-related purposes so population growth remains relevant.

INDUSTRIAL SELF-SUPPLIED WATER USE

EQUATIONS

No demand equations were statistically significant.

Freshwater consumption =

$$-21953 + 3335.4 \ln \text{GNP}$$
$R^2 = .989 \quad F = 374.7$

DISCUSSION

GNP was expected to be the most relevant independent variable for projecting industrial self-supplied water use. But regression equations could not be developed with GNP or any other independent variable in the data set that explained a significant portion of the variation in industrial self-supplied water withdrawals. Although GNP continued to grow at nearly the same rate as during the 1960s and 1970s, water pollution legislation and policy changes forced changes in withdrawals independent of continued growth in GNP. The change in withdrawals was so abrupt and happened so recently that statistically defensible projections of industrial self-supplied use cannot yet be made. Consequently, projections were based on simple time trends.

Projections assume that a major adjustment in water use occurred in the 1980s. Further, that industrial self-supplied use will soon resume growing at about 95% of the annual rate of growth between 1960 and 1980—roughly 275 mgd per year. This total rate of increase was disaggregated into 130 mgd per year in fresh surface water withdrawals, 90 mgd per year in groundwater withdrawals, and 54 mgd per year in wastewater withdrawals.

The consumption equation, however, explains virtually all the variation in consumption and is highly significant.

DOMESTIC SELF-SUPPLIED WATER USE

EQUATIONS

Total freshwater withdrawals =

$$-2535 + 28.089 \text{ population}$$
$R^2 = .94 \quad F = 58.8$

Groundwater withdrawals =

$$-2838 + 25.916 \text{ population}$$
$R^2 = .96 \quad F = 104.$

Fresh surface water withdrawals = no significant independent variable

DISCUSSION

Population was selected as the most relevant independent variable for explaining variation in rural domestic water withdrawals. The statistical analysis of fresh surface water withdrawals produced no significant independent variables, merely a highly significant intercept term. Consequently, surface water withdrawal estimates were computed as the difference between the projected total and projected groundwater withdrawals.

Statistical analyses of freshwater consumption yielded no significant equations. R-squared for the equations tested varied between .03 and .35 and the best F-statistic had a probability value of about .08. Thus, a combination of time and population trends were used to project freshwater consumption (fig. 30).

LIVESTOCK WATERING USE

EQUATIONS

Total freshwater withdrawals =

$$-12200 + 2650 \ln \text{population}$$
$R^2 = .96 \quad F = 72.8$

Groundwater withdrawals =

$$-6619 + 1446.32 \ln \text{population}$$
$R^2 = .87 \quad F = 19.53$

Fresh surface water withdrawals =

$$-5581 + 1203.68 \ln \text{population}$$
$R^2 = .95 \quad F = 53.6$

Freshwater consumption =

$$-8467 + 1919.02 \ln \text{population}$$
$R^2 = .90 \quad F = 26.5$

DISCUSSION

The 1985 livestock water withdrawal and consumption estimates are significantly different from previous estimates because aquaculture water use (fish farming) is included for the first time (fig. 33). Defining aquaculture as part of livestock water use is a major structural change in the data series. To eliminate effects of the structural change when estimating regression equations, 1985 estimates were not used. Consequently, the equations are

based only on the data from 1960 to 1980 and projections ignore future aquaculture water withdrawals and consumption.

Population was selected as the most relevant independent variable because it stands as a surrogate for red meat consumption. The basic assumption for red meat consumption for this Assessment was to hold per capita red meat consumption constant over the projection period. A similar case could be made for assuming per capita consumption of dairy products is constant over the projection period. Because per capita consumptions are constant, growth in the demand for animal products becomes a function of population.

Aquaculture water usage was relatively low from 1960 to 1980. Some states included aquaculture in the industrial self-supplied category; others in the livestock category. Between 1980 and 1985, the volume of water used in aquaculture grew rapidly as consumers ate more fish and poultry instead of beef and pork. Thus, USGS decided to standardize how states reported aquaculture water use declaring it an element of livestock use. This change in definition probably also contributed to difficulties in estimating industrial self-supplied water use equations. Sufficient data may be available by 1998 so the next RPA analysis of the water situation can include aquaculture in its livestock water projections.

APPENDIX C: SUMMARY OF STATE WATER QUALITY LAWS AFFECTING FORESTRY OPERATIONS

Significant features of water quality legislation are given, by region, in the tables that follow: South—Table C.1; North—table C.2; Rocky Mountain region—table C.3; and Pacific Coast region—table C.4 (source: Haines and Siegel (1988)).

Table C.1—Significant features of water quality legislation in the South

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alabama	Water Pollution Control Act Ala. Code, Sec. 22-22-1 to 14. Enacted 1971, amended 1973, 1979, 1982	Alabama Water Improvement Commission	Pollutants harmful to fish or wildlife, or constituting a public hazard are subject to regulation. Commission granted permit issuing authority for control of discharges of such pollutants into waterways. Commission may issue cease-and-desist orders and commence civil actions to enjoin actual or threatened violations	Civil: $100 to $10,000 fine per day of violation of a Commission rule or order. Criminal: $2,500 to $25,000 per day of violation and/or imprisonment for up to one year. Penalty may be doubled on second conviction. Payment of costs of damage, and restocking of fish and wildlife	No reference to silvicultural discharges or wastes from timber transport or harvesting. Law probably applicable to nonpoint pollution if damage to fish or wildlife clearly attributable	Coastal Preservation Act (Ala. Code, Sec. 9-7-14 to 9-7-22) Activities permitted include planting and harvesting of trees including normal road construction.
Arkansas	Water and Air Pollution Control Act. Ark. Stat. Ann. Sec. 82-1901 to 1991. Enacted 1949, amended 15 times, 1953 to 1985	Department of Pollution Control and Ecology (under authority of Arkansas Pollution Control Commission)	Department given broad authority to issue permits and orders, and to promulgate rules and standards, with respect to prohibited pollutants. Department can initiate civil action to force compliance with orders and standards	Civil: up to $5,000 fine per day of violation plus payment of administrative expenses and damages. Criminal: violation considered misdemeanor. Up to $10,000 and/or one year in prison per day of violation	Definition of pollution and Department's vested powers sufficiently broad to apply to nonpoint sources. Prohibited pollutants include decayed wood, sawdust, shavings, bark and sand. One member of the State Pollution Control Commission must be from the State Forestry Commission	Stream Obstruction Statutes (Ark. Stat. Ann. Sec. 41-4052 and Sec. 41-4066 to 41-4067) prohibit obstructing any improved drainage project or any natural drain with trees, tree tops or limbs. Tree Removal in Riparian Areas (Sec. 41-4068 to 41-4069) prohibits removal of trees growing below normal high water mark of any navigable river or stream
Florida	Air and Water Pollution Control Act. Fla. Stat. Ann. Sec. 403.011 to 403.291. Enacted 1971, amended 1972, 1974, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985.	Department of Environmental Regulation	Department given broad powers to develop water pollution abatement programs. Department must issue permits for all pollutant discharges pursuant to federal administrative requirements. Department may issue orders and seek injunctive relief against violations. Exception: Water owned entirely by one person excluded from Department control unless affecting other properties or water	Civil: up to $10,000 fine per day of violation. Criminal: Violation considered first degree misdemeanor. Fine of $2,500 to $25,000 and/or one year in prison per day of violation. False statement or misrepresentation: up to $10,000 and/or six months in prison. Department can initiate civil action to establish liability and recover damages, including those for fish mortality	Powers granted to Department are sufficiently broad to include regulatory authority over nonpoint pollution from land management activities	Warren Henderson Wetlands Protection Act of 1984 (Fla. Stat. Ann. T 29 Sec. 403.91 to 403.929) empowers Florida's five water management districts to regulate silvicultural activities which divert or impede normal water flow. Some districts require permits, others notification and/or merely compliance with standards
Georgia	Water Quality Control Act. Ga. Code Ann. Chap. 12-5-20 to 12-5-53. Enacted 1971, amended 1972, 1974, 1977, 1978, 1982, 1983, 1986	Division of Environmental Protection, within Department of Natural Resources (under authority of Georgia Water Quality Control Board)	Water Quality Control Board has broad authority to promulgate rules and regulations to control water pollution. Division of Environmental Protection can issue permits for both point and nonpoint discharges; can also issue stop orders. Statute applies to all waters except those entirely confined and retained on the property of a single ownership. All aspects of the program are to be consistent with the Federal Water Pollution Control Act	Civil: up to $25,000 fine per day of violation. Criminal: violation considered misdemeanor. Fine of $2,500 to $25,000 per day of violation and/or one year in prison. Penalty doubled for repeated offense. False misrepresentation: felony; up to $10,000 and/or two years in prison. Assessment of civil liability for damages.	Division of Environmental Protection has explicit authority to issue permits for discharge of nonpoint pollutants. 1978 amendment to Water Quality Control Act provides for state administration of Federal Water Pollution Control Act Section 404 permit program.	
Kentucky	Environmental Protection Law. Ky., Rev. Stat., Sec. 224.005 to 224.997. Enacted 1972, amended 1974, 1978, 1980, 1982, 1984	Bureau of Environmental Protection within the Department of Natural Resources and Environmental Protection.	Department has broad authority to issue water quality rules and regulations, and to issue discharge permits in accordance with Federal Water Pollution Control Act guidelines. Department may initiate court action against violations. Exceptions: exemptions may be granted for up to one year if discharge is not likely to have a measurable impact on water quality and/or compliance would produce undue hardship without equal or greater benefit to the public.	Civil: up to $10,000 fine per day of violation. Criminal: violation considered misdemeanor, fine of $1,000 to $15,000 and/or imprisonment for up to one year per day of violation. Payment of costs of damage, and restocking of fish and wildlife	Legislative authority broad enough to cover nonpoint pollution at discretion of Department. Department required to monitor environment for more effective and efficient control practices	Kentucky Wild Rivers Act (Ky. Rev. Stat., Sec. 146.200 to 146.350) permits only selective cutting of timber within boundaries of designated wild river areas. Stream Obstruction Statute (151.310 to 151.320) prohibits the deposit of any matter which disturbs the flow of water in streams without a permit

Louisiana	Water Control Law. La. Rev Stat 30 1073 and 30:1091–1097. Enacted 1979; amended 1980, 1983, 1984 1987.	Department of Environmental Quality and the Office of Water Resources (OWR)	The OWR is empowered to develop a general water protection plan and to regulate and restrain the discharge of pollution into waters. The Department establishes standards and guidelines; promulgates rules and regulations; and issues permits for the control of water pollution. Commission may initiate civil liability action.	No penalties may be imposed for unintentional pollution in connection with production of agricultural products. Commission may recover civil damages. Violations: polluting waters with substance which is not likely to endanger human life or health is a misdemeanor; punishable by a fine of up to $25,000/ day of violation and/or up to one year imprisonment. Polluting with a substance which could endanger human life or health is a felony punishable by a fine of up to $100,000/day and/or 10 years imprisonment. Civil penalties are up to $25,000/day of violation. Up to $50,000/day for failure to take corrective action after compliance order is issued.	Legislative authority broad enough to cover nonpoint pollution at discretion of Department. Specifically empowers the Department to develop a nonpoint source management program Law includes a provision prohibiting persons engaged in logging operations from leaving trees or treetops in navigable waters. Administrative regulations exempt silvicultural operations from permit requirements.	State and Local Coastal Resources Management Act of 1978 (La Rev Stat , Sec 49 213 1 to 49 13.22) Permits are not required for silvicultural activities when forest practices used consistently in the past are employed An experimental or unconventional practice might require a permit. Natural and Scenic River System Act (Sec 56.1841–1849 2) permits only selective cutting within 100 feet of scenic rivers Requires removal of tree tops from rivers
Mississippi	Air and Water Pollution Control Act Miss Code. Sec. 49–17–1 to 49–17–53. Enacted 1966; amended 1968, 1971, 1972, 1973, 1977, 1978, 1980, 1981, 1985	Commission of Natural Resources under authority of Bureau of Pollution Control of Department of Natural Resources.	Commission empowered to develop standards and programs for prevention, abatement and control of water pollution. A separate permit board issues permits for the discharge of contaminants Commission can issue cease-and-desist orders during an emergency.	Civil: up to $25,000 fine per day of violation. Criminal: $2,500 to $25,000 per day of violation. Commission can initiate civil action to recover actual damages.	Commission's powers are broad enough to be applied to nonpoint sources of pollution.	Stream Obstruction Law (Miss Code Sec 97–15–41) prohibits the felling of trees or leaving logs in excess of six inches in diameter or tree tops in a running stream
North Carolina	Water and Air Resources Acts N C Gen Stat Sec. 143–214 Enacted 1951; amended 1957, 1959, 1967, 1969, 1973, 1975, 1977, 1979, 1983, 1985	Department of Natural Resources and Community Development under authority of Environmental Management Commission.	Commission has broad powers over water pollution, is authorized to issue permits for discharge of pollutants, and can issue orders directed at a violator after a hearing is held.	Civil: up to $10,000 fine per day of violation. Criminal: violation considered misdemeanor, fine of up to $15,000 per day of violation, not to exceed a total of $200,000 for each 30- day period, and/or imprisonment for up to six months. Commission can initiate civil action to recover actual damages.	Sawdust and wood shavings are listed as potential pollutants in the law. Nonpoint pollutants are covered under the statute's definition of water pollution which includes "alterations resulting from the concentration or increase of natural pollutants caused by man-related activities".	Stream Obstruction statutes (N C. Gen Stat , Sec. 77–13 and 77–14) prohibit the felling of any tree, or the leaving of slash, stumpage, sawdust, shavings, etc. in any stream so as to obstruct drainage
Oklahoma	Pollution Control Coordinating Act Okla Stat Title 82, Sec 931 to 942. Enacted 1968, amended 1971, 1974, 1976, 1981, 1983 Pollution Remedies Law, Okla Stat. Title 82. Sec 926 1 to 926.13. Enacted 1972, amended 1981	Water Resources Board under authority of Pollution Control Coordinating Board	Department has executive authority over all state agencies administering pollution programs Definition of pollution is broad and includes those substances potentially injurious to aesthetic sensibilities Exception. law does not apply to waters entirely in one ownership unless affecting another's property or water.	Criminal. willful violation of any promulgated order is considered misdemeanor, punishable by maximum fine of $200 to $10,000 per day of violation and/or up to six months imprisonment Civil penalty: up to $10,000. Civil liability for damages lies with those responsible for violation.	Broad authority granted to Department of Pollution Control and Water Resources Board covers nonpoint source pollution.	
South Carolina	Pollution Control Act Code Laws S C Title 48, Sec 48–1–10 to 48–1–350 Enacted 1971, amended 1973, 1974, 1975, 1978, 1980	Department of Health and Environmental Control	Department charged with responsibility of administering all state programs under Federal Water Pollution Control Act. Department has permit issuing authority, and can promulgate rules and regulations. Can issue orders and initiate legal proceedings to force compliance Exception. no civil or criminal liabilities to be imposed for violations caused by acts of God, war, strike, riot, or catastrophe	Civil fine not to exceed $10,000 per day of violation. Criminal Violation considered misdemeanor; punishable by fine of from $500 to $25,000 per day of violation and/or imprisonment for up to two years. Department can initiate civil liability proceedings to recover costs of damage.	The statute addresses the term "pollutant" in its broadest sense, thereby presumably covering all nonpoint sources Statute specifically lists decayed wood, sawdust, shavings, bark and sand as potential pollutants	Stream Obstruction statute (Code Laws S C Title 49, Sec 1–20) prohibits streambank damage or obstructing waterways with felled timber Scenic Rivers Act (Title 51, Sec 5–120) prohibits timber harvesting within designated distances of Class 1 streams on state controlled lands Stream Cleaning Act (Title 49, Sec 1–30) requires landowners to clean out the streams adjacent to their properties twice a year and to keep them free of obstructions which would interrupt the flow of sand and water

Table C.1—Significant features of water quality legislation in the South—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Tennessee	Water Quality Control Act Tenn Code Ann Sec 69-3-101 to 69-3-121 Enacted 1971, amended 1972, 1973, 1977, 1979, 1981, 1982, 1984, 1985	Division of Water Quality Control (within Department of Public Health) under authority of Water Quality Control Board	Department of Public Health has broad authority to control water pollution, through regulations issued by Division of Water Quality Control Nonpoint pollution caused by agricultural and forestry activities are exempt from regulation Department of Public Health may issue cease-and-desist orders, and order corrective action	Civil up to $10,000 fine per day of violation. Criminal violation is considered misdemeanor; punishable by fine of $50 to $25,000 per day of violation Willful noncompliance, falsification of records, or misrepresentation considered felony and punishable by fine up to $25,000 and/or two years imprisonment Department of Public Health can assess civil damages	Pollution caused by agricultural or forestry activities subject to regulation only if point source involved Statute specifically lists decayed wood, sawdust, silt, shavings, bark and rock as potential pollutants (subject to regulation if point source).	Scenic Rivers Act of 1968 (Tenn Code Ann Sec 11-13-102 to 11-13-117) Commercial timber harvest is prohibited in protected river areas within conservation or public use easement
Texas	Water Quality Act. Texas Code Ann , Water Code, Title 2, Sec 5.001 to 5 357 and 26 001 to 26 225. Enacted in 1977; amended 1981, 1985	State Water Commission and State Water Development Board under the Department of Water Resources	Water Commission may grant authority to local governments to issue permits for discharge of waste into water Commission itself can also issue rules, regulations and orders to control water quality	Civil $50 to $10,000 fine per day of violation Criminal. $10 to $10,000 per day for violation of a rule or regulation.	The statute specifically covers agricultural waste, presumably including residues from forestry activities Statute specifically lists decayed wood, sawdust, shavings, bark, runoff from irrigation; and rainfall runoff from cultivated or uncultivated rangeland, pastureland and farmland that may impair water quality.	Stream Obstruction Act (Texas Code Ann Sec. 5 096) prohibits obstruction of navigable streams by cutting and felling of trees.
Virginia	Water Control Law. Code Va., Sec 62.1-44 2 to 62 1-44.42. Enacted 1973; amended 1974, 1976, 1977, 1978, 1980, 1981, 1984, 1985, 1986.	Water Control Board	After conducting a hearing, Board can issue special order to prohibit pollution, and also seek injunctive relief against violations	Civil: not to exceed fine of $10,000 per day of violation. Criminal $100 to $25,000 per day of violation. Civil action for damages may be initiated by Board if fish are killed as result of pollutant discharge.	Legislation is broad enough to cover nonpoint pollution Statute specifically lists decayed wood, sawdust, shavings and bark as potential pollutants.	Sec. 62.1-194 of the Virginia Code prohibits depositing timber or like material into any waters of the state. Sec. 62.1-194 2 of the Code prohibits placing treetops or logs which obstruct the movement of fish or boats for more than one week in rivers or streams. Scenic Rivers Act (Sec. 10-167 to 10-175). Permitted activities on rivers or river segments are designated on an individual basis. Forestry uses have not been restricted to date. Act specifies that the continuance of forestry activities on designated rivers is encouraged. Wetlands Act (Sec. 62.1-13.1 to 62.1-13.20) specifically permits the harvesting of forest products in wetlands.

Table C.2—Significant features of water quality legislation in the North

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Connecticut	Water Pollution Control Act Conn Gen. Stat Ann Title 22a Sec 416 to 471 Enacted 1958, amended 17 times, 1967 to 1987	Department of Environmental Protection	Department granted authority to develop plans for the prevention and control of water pollution Department adopts water quality standards and regulations in compliance with the Federal Water Pollution Control Act; and issues discharge permits. Department empowered to issue corrective orders	Civil. up to $10,000 fine per day of violation Criminal up to $25,000 fine and/or one year in prison per day of violation. False statement or misrepresentation: up to $10,000 fine and/or six months in prison	The statute's definition of water pollution includes alterations of water resulting in changes in turbidity or temperature which may be harmful to fish or other aquatic life Statute requires a permit for any discharge, regardless of whether or not the discharge may cause pollution.	River Protection Statute (Conn Gen Stat Ann. T.25 Sec. 102pp to 102vv). Municipalities granted authority to establish river protection corridors and may restrict land use Some towns along Connecticut River require forest management and sediment control plans for forest operations Inland Wetlands Statute (T.22a Sec. 361 to 363). Permit required for filling or reclamation of wetlands, road construction and clear-cutting of timber. Stream Obstruction Statute (T.22a Sec. 361 to 363). Permit required for placement of fill or obstruction in coastal, tidal or navigable waters Soil Erosion and Sedimentation Control Act (T.22a Sec. 326 to 329). Municipalities may adopt regulations to control erosion and sedimentation. Coastal Management Act (T.22a Sec. 90 to 112). Municipalities may issue zoning regulations for land use in coastal areas.
Delaware	Environmental Protection Act. Del. Code Ann. T.7 Sec. 6001 to 6060 Enacted 1953; amended 1982, 1983, 1984, 1985, 1986.	Department of Natural Resources and Environmental Control.	Department empowered to develop, administer and enforce pollution control programs. Department adopts rules and regulations and develops statewide water pollution management plan. Department issues permits for discharges and may grant variances to rules and regulations. Department also granted authority to publish a list of activities exempt from permitting procedure. Prior to issuance of permits, proposed activities must be approved by the county or municipality of jurisdiction through zoning procedures. Department may issue cease-and-desist orders for violations.	Civil: from $1,000 to $10,000 fine per day of violation. Criminal: from $50 to $500 fine per day for general violation of rule or regulation or permit condition. From $2,500 to $25,000 fine per day for willful or negligent violation. From $500 to $5,000 fine and/or six months imprisonment for false statement or misrepresentation. Department may initiate civil action to recoup cost of damages.	Authority granted Department is sufficiently broad to apply to nonpoint sources. Department list of activities exempt from regulation has not been published, to date. Rock, sand, decayed wood, sawdust, shavings, bark and agricultural wastes are listed as potential pollutants.	Sedimentation and Erosion Control Act (Del. Code Ann. T.7 Sec. 4001 to 4017) requires submission of sedimentation and erosion control plans for land disturbing activities. Most forestry operations are exempt from regulation. Pollution of Streams (T.7 Sec. 1112) prohibits the discharge of any wastes or deleterious substance in sufficient quantities to injure or destroy fish.
Illinois	Ill. Rev. Stat. Ch. 111 1/2 Sec. 1001 to 1052. Enacted 1970; amended 1972 to 1986, 14 times.	Environmental Protection Agency and Pollution Control Board	Board adopts rules and regulations and establishes water quality standards. Agency recommends regulations for adoption by Board and administers certification and permit systems Agency responsible for administering National Pollutant Discharge Elimination System program. Agency may take summary enforcement action and issue stop orders for violations.	Civil: up to $10,000 fine per violation and $1,000 per day of violation. Criminal. violations other than hazardous waste disposal: up to $25,000 fine per day of violation, in addition to any other penalties prescribed	Prohibits placing of any contaminants on land so as to create a water pollution hazard. Potential pollutants include wood residues, sand, silt, rock and agricultural wastes. Water quality standards developed to insure waters are free of floating debris and unnatural turbidity with potential to harm aquatic life.	Fish Protective Regulations (Ill Rev. Stat. Ch. 111 1/2 Sec. 1001 to 1052) prohibit deposit of wastes in waters or placing of wastes where they may wash into waters, which are harmful to aquatic life. Specifically prohibits deposit of trash, trees, or parts of trees in or along banks of water. Pollution of Streams (Ch. 34 Sec. 3116) grants authority to counties to prevent pollution and issue stop orders for the discharge of pollutants. Local Land Resource Management Planning Act (Ch. 85 Sec. 5803 to 5809) authorizes local government to adopt ordinances to control land use. Purpose of act includes forest land and natural resource conservation. Forest Preserves (Ch. 96 1/2 Sec 6308). Silvicultural activities are permitted in preserves. Prohibits deposit of debris, trees or tree limbs or shrubbery in or along banks of waters within preserves (state or county owned lands). River Conservancy Districts (Ch. 42 Sec. 383 to 410 1) requires the Board of Trustees of river conservancy districts to control pollution through their police powers Soil and Water Conservation District Law (T. 5 Sec 106 to 138.2). Directors of districts may adopt land use ordinances for the control of erosion and sedimentation and prevention of water pollution with the approval of three-quarters of district landowners in a referendum. Flood Water Control (Ch 19 Sec. 65 and 70) requires a permit for placement of woody plant material in or along banks of streams or for construction of stream crossings. Flood plains (Ch. 19 Sec 65F). Requires a permit for any type of construction in designated floodplains.

Table C.2—Significant features of water quality legislation in the North —Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Indiana	Stream Pollution Control Act Ind Stat Ann T 13 Sec 1-3-1 to 1-3-18 Enacted 1943, amended 1945, 1949, 1957, 1978, 1985, 1987	Stream Pollution Control Board and Department of Environmental Management	Board adopts rules and regulations and establishes standards for the discharge of pollutants Department issues permits for discharges Board may issue cease-and-desist orders and bring enforcement actions for violations	Civil action may be initiated for failure to comply with orders to cease polluting activities within 60 days of issuance Additional civil penalty of $100 per day of violation past date specified in order or for additional days granted Criminal violations are Class B misdemeanor and subject to fine of up to $1,000 and/or 180 days imprisonment	Act prohibits any discharges which may impair fish life Broad definition of pollutant includes both organic and inorganic matter which is disposed of in any way into waters, including runoff and seepage	Stream Obstruction Statutes (Ind Stat Ann T 14 Sec 2-5-9 and T 13 Sec 2-4-4) prohibit the obstruction of any navigable waters or other water way which prohibits the free passage of fish Scenic and Recreational Rivers Preservation Act (T 13 Sec 2-26-1 to 2-26 11) requires approval of the Department of Natural Resources Commission prior to harvesting below the high flood mark of designated rivers which may be up to 200 feet River Commission Act (T 13 Sec 2-27-1 to 2-27 27) Activities which significantly alter the natural and scenic qualities of designated rivers are generally prohibited Individual river commissions have authority to issue permits for activities otherwise prohibited Exception to permitting authority activities visible from five feet above water surface Flood Control Act (T 13 Sec 2-22-1 to 2-22-20) prohibits obstruction of any floodway which could adversely affect fish, wildlife or botanical resources
Iowa	Water Quality Act Iowa Code Ann Sec 455B 171 to 455B 210 Enacted 1965, amended 13 times, 1969 to 1986	Department of Natural Resources and the Water Pollution Control Commission	Commissioner establishes water quality standards and rules for discharges in accordance with the Federal Water Pollution Control Act Department enforces rules and standards and issues permits Department authorized to issue cease-and-desist orders	Civil up to $5,000 per day of violation Civil penalty provided in Act as alternative to criminal Criminal up to $10,000 per day of violation Repeated offense up to $20,000 per day of violation False statement or misrepresentation up to $10,000 and/or six months in prison	Definition of water pollution includes any alteration or contamination which is injurious to fish or other aquatic life Act authorizes local governments to adopt ordinances and regulations for land use in flood plain areas	Erosion Control Law (Iowa Code Ann Sec 467A 2 to 467A 75) Erosion control plan not required for timber harvest However, operations must not exceed soil loss limits established for each district Logging road construction may require erosion control plan if more than 25 000 square feet of soil are disturbed Sec 109 14 prohibits the obstruction of waters which impede the free passage of fish Scenic Rivers System Act (Sec 108A 1 to 108A 7) authorizes political subdivisions to zone or otherwise establish land use controls along designated rivers
Maine	Protection and Improvement of Waters Act Maine Rev Stat Ann T 38 Sec 361 to 489 Enacted 1954, amended 12 times, 1957 to 1985	Board of Environmental Protection and municipalities under authority of the Board	Board charged with the control and prevention of water pollution Board issues permits and licenses, establishes water quality standards and parameters for the classification of waters Board also establishes criteria for mixing zones required for the dilution of pollutants	Civil from $100 to $10,000 fine per day of violation Criminal up to $25,000 per day of violation False statement or misrepresentation up to $10,000 and/or six months in prison Court may order restoration of site	Statute includes sand, dirt, rock and agricultural wastes of any kind as potential pollutants Prohibited deposits include sawdust, chips, bark and other forest products refuse Permit may be required for operations conducted below high water mark of ponds over ten acres and in protected river corridors In wetlands, "normal and customary" forest practices are exempt from permit requirement Log driving is prohibited and the storage of logs in waters requires a permit Permit required for dredge and fill operations and for construction of permanent structures within or adjacent to streams or rivers when spoil, fill or structure may wash into waters Under Shoreline Zoning, (Sec 435 to 447) timber harvesting within 250 feet of normal high water mark of waters, but not associated road construction, is exempt from permit requirements. Timber harvesting is prohibited within shorelands of ponds larger than ten acres in resource protection districts Creation of clearings within 50 feet of the high water mark of a shoreline is also restricted	Coastal Management Policies (Maine Rev Stat Ann T 38 Sec 1801 to 1803) establishes general policies for the protection of coastal resources, with potential application to forestry Maine Land Use Regulation Law (T 12 Sec 681 to 689) authorizes Land Use Regulation Commission to issue rules, regulations and standards for land use in unorganized townships Harvesting and road construction may require permit and/or compliance with standards Standards limit clearcut size and restrict slash disposal Regulations require control measures be used to minimize sedimentation and erosion during road and stream crossing construction

Maryland	Water Pollution Control and Abatement. Ann Code of Md T 8 Sec 1401 to 1502 Enacted 1957. amended 13 times. 1973 to 1987	Department of the Environment	Department is responsible for development and implementation of pollution control programs. Department adopts rules and regulations. establishes water quality standards. and issues permits Department may order corrective actions for violations	Civil up to $10,000 fine per day Criminal violation considered misdemeanor Fine of up to $25,000 per day and/or imprisonment for up to one year Penalty doubled for repeated offenses Falsification or misrepresentation fine of up to $10,000 and/or six months in prison	Statute prohibits the emission of soil or sediment into waters or placement of soil or sediment where it is likely to be washed into waters by runoff of precipitation or by any other flowing waters	Scenic and Wild Rivers Act (Ann Code of Md T 8 Sec 401 to 411) Harvesting in some river corridors is regulated by local ordinances Sediment Control Act (T 8 Sec 1101 to 1104) Sediment control plan for harvests disturbing 5,000 square feet or more of soil or which cross watercourses with drainage area in excess of 400 acres (100 acres for trout streams) Watershed Sediment and Waste Control (T 8 Sec 1201 to 1210) Permits required for excavating, grading or filling operations in Severn or Patuxent watersheds Chesapeake Bay Critical Area (T 8 Sec 1801 to 1816) applies to all land within 1,000 feet of mean high tide Commercial harvests require approval of forest mgmt & sediment control plans by district forestry board Harvesting prohibited within 50 feet of tidal waters and perennial streams Clearcutting other than loblolly pine or tulip poplar prohibited within 100 feet of these waters. road construction regulated too
Massachusetts	Clean Waters Act. Mass Gen. Laws Ann. Chap 21, Sec 26 to 53 Enacted 1966, amended 14 times, 1967 to 1985	Division of Water Pollution Control within the Department Environmental Quality Engineering	Division has broad authority to promulgate rules and regulations. establish minimum water quality standards, and issue permits Division may also issue cease-and-desist orders against violators	Civil: up to $10,000 fine per day of violation Criminal fine of $2,500 to $25,000 and/or one year in jail Department may order corrective action for violations	Statute's definition of "pollutant" includes any element of agricultural, industrial or commercial waste, including runoff, whether originating at a point or major non-point source Regulations exempt silvicultural operations including road construction from which there is natural runoff Act specifies, however that some silvicultural operations, such as stream crossings for roads, may require a Section 404 permit	Scenic and Recreational Rivers and Streams (Mass Gen Laws Ann Chap 21 Sec 17B) Counties may regulate, restrict or prohibit activities which could alter or pollute protected rivers and streams Ordinances could be adopted to restrict silvicultural activities Protection of Coastal Wetlands (Chap 130 Sec 105) Activities which involve dredge or fill or otherwise alter or pollute lands subject to tidal action may be regulated, restricted or prohibited Alteration of Lands Bordering Waters (Chap 131 Sec 40) requires written notice of intent to fill, dredge, or alter freshwater or coastal wetlands or any land subject to tidal action and a plan describing activities and their effect on the environment Pollution of Coastal Waters (Chap 130 Sec 23 to 27) prohibits discharge of injurious substances, including sawdust and shavings, which directly or indirectly injure fish in coastal waters Forest Cutting Practices Act (Chap 132 Sec 40–46) requires Intent to Cut/Cutting Plan for harvesting Also requires additional wetlands or steep slopes plan if applicable Wetlands plan exempts operations from state Wetlands Law (Chap 131 Sec 40) Regulations address harvesting systems, skid trail location, stream crossing and road construction Also limit clearcut size and require buffer and filter strips along streams Additional rules for wetlands and steep slopes
Michigan	Act establishing Michigan Water Resource Commission Michigan Compiled Laws, Title 3 Sec 520 to 532 Enacted 1929, amended 1941, 1947 1949, 1963, 1965, 1968, 1972, 1977	Michigan Water Resources Commission	Commission authorized to regulate the storage or discharge of any substance which may affect water quality Commission establishes water quality standards and issues permits for discharges Commission has control over alterations of watercourses, floodplains, rivers and streams and may prohibit their obstruction Act prohibits filling or grading lands located in flood plains or streambeds except for agricultural purposes, without a permit Copper or iron mining operations may be exempted from this provision	Civil up to $10,000 fine per day of violation Criminal from $2,500 to $25,000 fine per day of violation Penalty doubled for repeated offense Violator liable for restitution of damages to natural resources Courts may impose probation in addition to fines	Act prohibits discharge of any substance which is injurious to the value or utility of riparian lands or to fish aquatic life or plants	Stream Obstruction Statutes (Mich Compiled Laws T 9 Sec 334, T 13 Sec 1657 T 9 Sec 1175, T 18 Sec 231) prohibit obstruction of streams or navigable waters with logs lumber apparatus or waste materials which prevent the free passage of fish or obstruct navigation Soil Erosion and Sedimentation Control Act of 1972 (T 13 Sec 1820(1) to 1820(17)) Counties delegated authority to enforce rules and regulations issued by the Commission and issue or deny permits for activities which may result in erosion or sedimentation Empowers local governments to adopt more stringent requirements than issued by Commission Act exempts logging from regulation However, stream crossings constructed to conduct operations may require a permit Shorelands Protection and Management Act (T 13 Sec 1831 to 1845) empowers Commission and local governments to adopt rules for land use along Great Lakes shorelands Commission rules may restrict cutting or vegetation requires buffer

Table C.2—Significant features of water quality legislation in the North—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
						strips be retained and/or management plans in designated areas Inland Lakes and Streams Act (T 11 Sec 475 (1) to 475 (15) requires a permit for activities which (1) dredge or fill bottomland, (2) place a structure in bottomland, or (3) structurally interfere with natural flow of inland lake or stream Permit required for both temporary and permanent stream crossing Natural Rivers Act of 1970 (T 11 Sec 501 to 516) Counties and townships may require a permit or restrict or prohibit cutting timber along some rivers Act limits restricted corridor to 100 feet Gaemaere-Anderson Wetlands Protection Act (T 18 Sec 595 (51) to 595 (72)) exempts silviculture, lumbering, and harvesting of forest products from permit requirements Act also exempts minor drainage to improve site for silviculture or lumbering
Minnesota	Water Pollution Control Act Minn Stat Ann Sec 115 01 to 115 83 Enacted 1961, amended 15 times 1963 to 1987	Minnesota Pollution Control Agency	Agency granted broad powers to establish rules and standards and issue permits and orders for pollution control Enforcement powers include actions to recover civil penalties injunctions and actions to compel performance	Criminal violations considered misdemeanor Fine from $300 to $40,000 per day and/or one year imprisonment Second conviction up to $50,000 per day and/or two years imprisonment Civil up to $10,000 fine per day of violation Exempted from civil liability are acts of God, war negligence of the state, or sabotage or vandalism	Definition of "other wastes" includes sawdust, shavings, bark, sand and agricultural wastes Pollutants include any discharges which are harmful to fish or other aquatic life	Pollution of Waters Act (Minn Stat Ann Sec 144 35) and Work in Public Waters Act (Sec 105 42) prohibit the deposit of any sewage or other material which will impair the health of water or placing materials where they may fall or drain into a pond or stream Sec 105 42 includes excavation or filling activities Public Waters and Wetlands Act (Sec 105 37 to 105 391) empowers state to regulate activities which will change the course current or cross-section of wetlands or public waters Prohibits draining wetlands unless replaced with wetlands of equal or greater value Silviculture not exempted. Any physical change below high water mark would require a permit, including logging road and skid trail construction and associated bridges and culverts. Shoreland Development Act (Sec 105 485) requires counties and municipalities to adopt an ordinance for use and development of shorelands consistent with state model ordinance and rules Current rules emphasize destruction of view Proposed rules for silviculture include (1) maintaining buffer strips adjacent to waters, (2) restrictions for landing and yarding areas and skid and haul roads, (3) prohibition of clearing of vegetation on slopes 30 percent or greater, (4) requiring prompt reforestation, and (5) requiring permit and erosion control plan for forest conversions Excessive Soil Loss Act (Sec 40 19 to 40 27) encourages local governments to adopt soil loss ordinances consistent with state model and minimum standards Forestry included as an "agricultural activity" in rules A plan may be required for restoring erosion damage after harvest if soil loss is excessive County Planning and Zoning Act (Sec 394 21 to 394.26) grants authority to Board of County Commissioners to establish zoning districts for land use, including forestry. Floodplain Management (Sec 104 01 to 104 07) encourages local governments to adopt ordinances for land use in flood-plains Ordinances restrict fill, deposit or other use which unduly restrict the capacity of floodplains Some counties require permit for logging road construction in floodplains. Wild and Scenic Rivers Act (Sec 104 31 to 104 40) State rules prohibit clearcutting within designated distances of rivers depending on river classification Trees greater than four inches in diameter may be removed provided continuous tree cover is maintained County regulations may be adopted which are more restrictive than state.

Missouri	Clean Water Act Ann Missouri Stat T 12 Sec 644 006 to 644 141 Enacted 1972, amended 1973, 1982, 1983, 1987	Missouri Clean Water Commission and Department of Natural Resources.	Commission granted broad powers to issue orders and permits Commission adopt and enforce rules and regulations, and prescribes water quality standards. Department may initiate civil action to force compliance with standards and rules.	Criminal: $2,500 to $25,000 fine and/or one year imprisonment per day of violation Subsequent convictions. up to $50,000 fine and/or two years imprisonment False statement or misrepresentation: up to $10,000 fine and/ or six months imprisonment. Civil: up to $10,000 fine per day of violation. Action may be brought to restore damages.	Definition of pollution includes alterations of water turbidity and contamination which is harmful to fish and other aquatic life. Act states that contamination includes both direct and indirect sources including surface runoff. Commission authorized to conduct a planning process to identify silvicultural nonpoint sources of pollution and to develop procedures and methods, including land use requirements, to control sources.	Steam Obstruction Statute (Ann. Missouri Stat., T 16 Sec. 252 200) prohibits obstructing the free passage of fish through any waters of the state. Water Conservancy District Act (T.16, Sec. 257.010 to 257 490) empowers citizens to form river basin conservancy districts through which land use may be regulated.
New Hampshire	Water Pollution and Disposal of Wastes Act N.H R.S. Ann Sec 149:1 to 149:26. Enacted 1947, amended 11 times, 1955 to 1986	New Hampshire Water Supply and Pollution Control Commission	Commission has broad authority for the discharge of pollutants in waters and alterations near waters. Commission issues permits, promulgates rules and regulations, and classifies waters into one of four quality types. Commission may issue cease-and-desist orders.	Civil: up to $10,000 fine per day of violation. Criminal. up to $25,000 fine per day and/or six months in prison.	Act includes decayed wood, sawdust, bark, shavings and other substances harmful to human, animal, fish or aquatic life as potential pollutants. Prohibits placing trees or parts thereof in waters. Detailed plans must be submitted for forest operations in lands bordering water. Upon approval of the Commission, a permit will be issued. Requirement can be circumvented by signing of an agreement to implement appropriate BMP's to protect water quality. If operator fails to comply with BMP's, he is subject to penalties under the law and will be required to submit detailed plans for future operations.	Fill and Dredge in Wetlands (N.H.R.S. Ann. Sec. 483-A:1 to 483-A:7) requires permit for some activities in wetlands such as construction of stream crossings. Slash and Mill Waste (Sec. 224:44-b) prohibits disposal of slash in waters or within 25 feet of streams or rivers capable of float-ing a canoe or within 50 feet of navigable rivers or ponds greater than 10 acres. Limits slash dispos-al to 4 feet above ground between 50 and 150 feet of ponds greater than 10 acres or navigable streams or rivers. Cutting of Timber near Public Waters and Highways (Sec. 224: 44-a) limits cutting of trees to 50 percent of basal area within 150 feet of ponds greater than ten acres and navigable streams and rivers or within 50 feet of any other continuously flowing stream or river
New Jersey	Water Pollution Control Act N J Stat Ann T 58 Sec 10A-1 to 10A-37 Enacted 1977, amended 1981, 1984, 1986	Department of Environmental Protection.	Commissioner of Department of Environmental Protection empowered to adopt rules and regulations, classify bodies of water and establish water quality standards for each class, and issue permits. Commissioner may, by regulation, exempt certain discharges from permit requirements. Possible exemptions include: (1) Uncontrolled nonpoint source discharges composed entirely of stormwater runoff; (2) nonpoint discharges in general, and (3) discharges of dredge and fill material.	Civil: up to $50,000 fine per day of violation. Criminal: fine of $5,000 to $50,000 and/or six months imprisonment per day of violation. Penalty doubled for repeated offense. False statement or misrepresentation: up to $20,000 fine and/or up to six months imprisonment Assessment of civil liability for damages.	Act defines pollutants to include dredged spoil, rock, sand, agricultural waste or other residue. Silvicultural nonpoint source pollution could be exempted at the discretion of the Commissioner through regulations.	Flood Hazard Area Control Act (N.J. Stat. Ann. T.58 Sec. 16A-50 to 16A-66) requires permits for land disturbing activities affecting more than 5,000 square feet in flood hazard areas. Logging road construction may require a permit for extensive operations. Stormwater Management Plan (T.40 Sec. 55D-93 to 99). Municipalities required to adopt ordinances to minimize stormwater runoff and control nonpoint source pollution. "Nonpoint pollutants" include silvicultural sources. To date, ordinances have not been adopted. Soil Erosion and Sediment Control Act (T.4 Sec. 24-39 to 24-55). Soil Conservation Committee establishes standards and may require plans for the control of sedimentation and erosion from land disturbing activities involving 5,000 square feet or more of soil. To date, plans have not been required for silvicultural operations. Could be applied when large areas are disturbed during logging road construction. Wild and Scenic Rivers Act (T.13 Sec. 8-45 to 8-54) Department of Environmental Protection establishes minimum standards for land use in river corridors. Municipalities may adopt rules and regulations more stringent than Department To date, no regulations or standards have been adopted Pinelands Protection Act (T 13 Sec 18A-1 to 18A-49) applies to approximately one million acres Pinelands Commission requires harvesting plan be approved by the Bureau of Forestry prior to issuance of a permit by the Commission Act prohibiting the draining of deleterious substances into waters (T 23 Sec 5-28 to 5-29 1) exempts application of chemicals on forest crops Freshwater Wetlands Act(T 13 Sec 9B-1 to 30) regulates dredging, draining, filling, and other alterations of freshwater wetlands, including cutting of trees Exempt from permitting process are "normal" silvicultural operations, includes harvesting and road construction in compliance with BMP's and a management plan approved by State Forester Conversion of wetlands to manipulate tree species composition not exempt.

Table C.2—Significant features of water quality legislation in the North—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
New York	Water Pollution Control Act. Cons Laws of N Y Art 17 Sec 0101 to 1907 Enacted 1972, amended 12 times, 1973 to 1987.	Department of Environmental Conservation	Department determines classifications of waters and adopts standards of quality and purity for each class Department adopts rules and regulations to prevent pollution and issues permits Department authorized to issue cease-and-desist orders for violations.	Civil up to $1,000 fine per violation Criminal fine from $2,500 to $25,000 per day of violation and/or one year imprisonment Penalty double for repeated offenses	Potential pollutants include substances which may be harmful to aquatic life Prohibited "industrial wastes" include substances resulting from the development or recovery of any natural resource, which may be a potential pollutant Prohibited "other wastes" include sawdust, decayed wood, shavings and bark Act prohibits the discharge of both organic and inorganic matter which is not in compliance with Department standards	Wild, Scenic and Recreational Rivers (Cons Laws of N Y Art 15 Sec 2701 to 2723) Regulations require a permit for clearcuts in excess of 25 acres and include numerous rules for road and stream crossing construction, felling and skidding trees, debris removal, and buffer strips in river corridors Fish and Wildlife Law (Art 11 Sec 0501 to 0536) Act prohibits the deposit of sawdust, shavings, or bark in waters in amounts which would harm fish or wildlife Prohibits obstruction of waters which hinder the passage of fish Prohibits the deposit of soil in streams or on banks of streams inhabited by trout Freshwater Wetlands Regulations (Art 24 Sec 0701 to 0705) Act regulates draining, dredging or filling of freshwater wetlands Permits required for clearcuts within wetlands, but are usually not granted. Selective cutting is exempt from regulation. Clearcuts in areas adjacent to wetlands require permit, and are usually granted Stream Protection Law (Art. 15 Sec 0501 to 0503) Act requires a permit for changing, modifying, or disturbing streams or banks of streams within designated water classifications Excavation or fill in navigable waters (Art 15 Sec 0505) requires permit for excavation or fill below the high water mark of navigable waters and in adjacent wetlands or marshes.
Ohio	Water Pollution Control Act. Ohio Rev. Code Ann. Sec 6111 01 to 6111 99) Enacted 1953, amended 14 times, 1955 to 1984	Department of Environmental Management	Department promulgates rules and regulations and establishes water quality standards Department issues permits and orders for pollution control. Act prohibits placing any waste in a location where water pollution could result without a permit. Exception application or runoff of materials used for agricultural purposes Department may seek injunction against violators	Criminal up to $25,000 fine and/or one year imprisonment	Definition of pollutant includes decayed wood, sawdust, bark shavings, other wood debris and silt	Pollution Control Program (Ohio Rev Code Ann Sec 1501 20) requires Soil and Water Conservation Commission to develop program for agricultural pollution abatement to meet state water quality standards Commission currently has no enforcement power Department of Natural Resources is seeking amendment for $100 fine per day for pollution resulting from agricultural (including silvicultural) sedimentation Watershed District Law (Sec 6105 01 to 6105 99) prohibits obstruction of restricted floodway without consent of Board of Directors of watershed districts
Pennsylvania	Clean Streams Act Penna. Stat. Ann. T.35 Sec. 691 1 to 691.1001. Enacted 1937; amended 1945, 1956, 1965, 1970, 1976, 1978, 1980	Department of Environmental Resources and Environmental Quality Board	Department has broad authority to adopt rules and regulations and establish standards to control pollution Department issues permits for discharges and may seek injunctions and issue orders for abatement of polluting activities	Civil: up to $10,000 fine per day of violation Criminal: from $100 to $10,000 fine for violation Default of payment. 90 days imprisonment Willful or negligent violations from $2,500 to $25,000 fine and/or one year imprisonment Additional offense within two years of first offense from $2,500 to $50,000 fine and/or two year imprisonment.	Act defines pollution to include contamination which is injurious to fish or other aquatic life and alterations resulting in changes in water temperature. Exempt from penalties is pollution in the form of sediment resulting from an act of God on land for which an approved conservation plan has been implemented By inference, other causes of sedimentation, including that resulting from forest operations, would be subject to regulation Under regulations issued under the Act, detailed, site specific plans are required for erosion and sedimentation control for silvicultural operations where earth disturbing activities exceed 25 acres	Flood Plain Management Act (Penna Stat Ann T 32 Sec 679 101 to 679 601) Plans to control obstruction of flood waters implemented by local governments Some may regulate forest operations Storm Water Management Act (T 32 Sec 680 1 to 680 17) Local governments may enact ordinances for the control of runoff and sedimentation and erosion Some may regulate forest operations Dam Safety and Encroachment Act (T 32 Sec 693 1 to 693 27) Permit required for both permanent and temporary water crossings constructed during harvesting operations Scenic Rivers Act (T 32 Sec 820 21 to 820 29) Recommended guidelines for silvicultural operations have been issued Protection of Property and Water Act (T 30 Sec 2501 to 2506) Permits required for activities which alter streams, water or watersheds in any way which may damage fish.

Rhode Island	Water Pollution Control Act Gen Laws of R I. T.46 Sec 12-1 to 12-37 Enacted 1920, amended 24 times, 1921 to 1986	Department of Environmental Management	Department empowered to adopt standards and issue rules and regulations for the control of water pollution Department classifies waters and issues permits for the discharge of pollutants Department has authority to issue stop orders for violations	Civil up to $5,000 fine per day of violation Criminal: up to $10,000 fine and/or 30 days imprisonment per day of violation. False statement or misrepresentation: up to $5,000 and/or 30 days imprisonment.	Act defines pollutant to include agricultural wastes Legislation is sufficiently broad to cover nonpoint sources of pollution Act prohibits placing any pollutant where it is likely to enter waters or to place any solid waste materials, junk or debris whether organic or inorganic in waters	Soil Erosion and Sediment Control Act (Gen Laws of R I T 45 Sec 46-1 to Sec 46-6) Cities and towns may require permits for earth disturbing activities Act exempts harvest activities on property utilized for silvicultural purposes Road construction may require a permit and erosion control plan if extensive or if involving slopes greater than ten percent Freshwater Wetland Act (T 2 Sec 1-18 to 1-27) prohibits excavation, draining or filling of wetlands Also prohibits placing garbage, earth, rock, sand or other materials in waters Harvesting operations may require a management plan, depending on extent of operations
Vermont	Water Pollution Control Act V S A T 10 Sec 1250 to 1384 Enacted 1947, amended 15 times, 1949 to 1987	Vermont Resources Board and Department of Water Resources and Environmental Engineering within the Agency of Environmental Conservation	Act establishes classification parameters for waters Board adopts standards of water quality for various classes Agency establishes rules and regulations for pollution control and has authority to issue permits Act addresses stormwater runoff and alteration of wetlands. Agency authorized to bring suit to force compliance with Act and may order corrective action for violations	Civil: up to $10,000 fine per day of violation. Criminal: up to $25,000 fine and/or six months imprisonment per day of violation. Falsification or misrepresentation: up to $10,000 fine and/or six months imprisonment Sawmill Waste: $100.00 fine per offense.	Act prohibits deposit of sawdust, shavings, edgings, slabs or other sawmill refuse into waters or placing wastes in such a manner as to wash into waters Forest operations must comply with acceptable management practices (AMP's) to be exempt from permitting requirements under Act Department of Forests, Parks and Recreation issues AMP's	Protection of Navigable Waters and Shorelands Act (V S A Sec 1421 to 1426) Municipalities authorized to adopt shoreland zoning bylaws to control pollution and protect fish and aquatic life Some forest operations may be restricted Water Resources Management Act (Sec 901 to 923) grants broad authority to Water Resources Board for protection of wetlands Board may not adopt rules which restrain silvicultural activities without consent of the Department of Forests Parks and Recreation An Act Relating to Regulation of Wetlands (Senate Bill 95 No 188) Sections related to forestry duplicate Water Resource Management Act Rules and regulations currently being developed will restrict some forest operations such as draining wetlands to harvest and road and stream crossing construction in wetlands
West Virginia	Water Pollution Control Act W Va. Code, Chap 20, Art 5A-1 to 5A-21 Enacted 1969, amended 1976, 1978, 1983	Division of Water Resources (within Department of Natural Resources) under authority of Water Resources Board	Division of Water Resources is authorized to carry out requirements of Federal Water Pollution Control Act, has permit issuing authority and may issue stop orders Exception law does not apply to farm ponds, industrial settling ponds and water treatment facilities	Civil: fine not to exceed $10,000 per day of violation. Fine can be imposed only by civil action initiated in circuit court of county where violation occurs. Criminal. violation considered misdemeanor; punishable by fine of $100 to $25,000 per day of violation and/or up to one year in jail Department of Natural Resources can initiate court action to recover costs of damage.	Law is sufficiently broad to include nonpoint pollutants under its provisions Decayed wood, sawdust, shavings, and other wood residues are specifically listed as potential pollutants Stringent water turbidity standards have been established Exceptions for logging have been made where a site specific BMP plan is in effect	Stream Obstruction Law (W Va Code Chap 61 Art 3-47) prohibits any felling of timber that would obstruct a navigable or floatable stream Natural Stream Preservation Act (Chap 20 Art 5B-1 to 17) prohibits activities which obstruct the free-flowing characteristics of designated streams without a permit Act has not been applied to forest operations to date

Table C.2—Significant features of water quality legislation in the North—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Wisconsin	Water and Sewage Act Wis Stat Ann Sec 144 01 to 144 27 Enacted 1913, amended 15 times, 1919 to 1986	Department of Natural Resources	Department has broad authority for supervision and control over state waters Department develops regional plans, establishes water quality standards, adopts rules and regulations, and issues permits for discharges Department may issue temporary emergency orders to protect public health and stop orders for abatement of pollution Department required to prepare comprehensive plan for application of municipal ordinances regulating navigable waters and shorelands Act authorizes municipal construction site erosion control and storm water management zoning ordinances Department required to develop standards for ordinances	$200 to $5,000 fine per day of violation	Prohibits the disposal of garbage or refuse where it is likely to be washed into water Prohibited are discharges which are deleterious to fish and unnecessary siltation resulting from gross neglect of land erosion Act establishes a nonpoint source pollution program providing technical and financial assistance Department promulgates rules and standards concerning BMP's which must be met for cost sharing grants	Wetlands Zoning Act (Wis Stat Ann Sec 61 351) requires villages to enact ordinances consistent with Department of Natural resources (DNR) minimum standards to protect shorelands Access roads and stream crossings for logging operations may require permit and/or be subject to DNR standards Shoreland Zoning on Navigable Waters Act (Sec 59 971) requires counties to enact zoning ordinances to protect shorelands within 1,000 feet of lakes and ponds and 300 feet from rivers and streams Clearcuts are limited to 30 feet for each 100 feet along shorelands within a 35 foot corridor Slash Disposal Act (Sec 26 12) requires timber owners or operators to remove logging slash from lakes and streams Environmental Impact Statement (EIS) Act (Sec 23 40) DNR determines whether EIS required based on information submitted when applying for permit Permit required for stream crossing, therefore would be subject to review Soil and Water Conservation Law (Sec 92 02 to 92 16) requires Department of Agriculture to develop model ordinances for land use for adoption by counties and municipalities Local ordinances may restrict land management practices which cause excessive erosion, sedimentation, nonpoint source pollution, or stormwater runoff Ordinances must be approved in referendum Wild Rivers Act (Sec 30 26) designates Pike, Pine and Popple rivers for preservation Requires DNR to work with counties and towns to establish program for river protection Requires DNR to cooperate with USFS, timber companies, and private landowners in implementing land use practices Some ordinances restrictive to forest practices have been adopted Lower St Croix River Preservation Act (Sec 30 27) requires local governments within designated protected areas to enact zoning ordinances in compliance with DNR guidelines and standards Some ordinances have been restrictive to forest operations. Obstruction of Navigable Waters (Sec 30.15) prohibits placing any obstruction in navigable water or tributaries which impedes navigation Enlargement and Protection of Waterways Act (Sec 30.19). Prohibits grading or otherwise removing top soil from banks of navigable waters which expose more than 10,000 square feet Exempts agricultural land use. Changing of Streamcourse Act (Sec 30.195) prohibits changing of course or straightening of navigable streams without permit Under authority of Sec 30 15, 30 19, and 30 195, both temporary and permanent stream crossings associated with logging require a permit.

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Arizona	Ariz Rev Stat Ann Sec 49-201 to 321 resulting from additions, transfers and renumbering from Title 36 (enacted in 1956 with subsequent amendments). Enacted in 1986, effective 1987.	Department of Environmental Quality	Department to promulgate water quality standards for all navigable waters, and develop a program for control of nonpoint source pollution into such waters As part of this program, Department may establish BMP's for silvicultural activities Forestry operations may require either individual or general permit at Department's option Department may issue order requiring initiate compliance with statutory provisions, order will become final and enforceable within 30 days unless administrative hearing is requested Department may request a temporary restraining order, preliminary or permanent injunction, or any other relief necessary to protect public health	Civil penalties up to $25,000 per day per violation plus costs of litigation Monetary damages to be paid to water quality assurance revolving fund Criminal penalties range from felony to misdemeanor depending upon whether the violator was fully knowledgeable, negligent, or reckless Violators may also be responsible for remedial action costs	Sections R9-21-202 to 205 of Administrative Rules and Regulations of Arizona 1986 prohibit water quality degradation Otherwise, Department has no non-point source program beyond water quality standards No forestry BMP's have been developed and none are expected. Only standards likely to affect forestry practices are turbidity and temperature Regulations governing use of agricultural pesticides currently under development for protection of groundwater.	Ariz. Rev Stat. Ann. Sec. 17-231, 237; requires cooperation between Department of Environmental Quality and Game and Fish Commission in abatement of water pollution injurious to wildlife Commission may also bring suit in such matters. Ariz Rev. Stat Ann Sec. 45-573 requires cooperation between Department of Environmental Quality and Department of Health Services on development of water quality management plans.
Colorado	Colorado Water Quality Control Act. Colo Rev Stat Sec 25-8-101 to 703 Enacted 1973, supplemented 1986	Department of Health through Water Quality Control Commission.	Policy objectives of legislation are two-fold: (1) protect quality of water resources, and (2) maximize the beneficial use of water resources consistent with the welfare of the state Act does not supersede or materially diminish prior established water rights Water Quality Commission within Department has authority to classify waters and promulgate water quality standards to control pollution In developing standards, Commission is directed to consider whether pollution is from a natural source Commission may promulgate regulations for the keeping of logs in water. Commission may not adopt standards for agricultural nonpoint sources of discharge which materially injure existing water rights Department is to administer standards and programs developed by Commission Department required to establish permit system for regulation of point sources of pollution, there are no particular provisions governing nonpoint sources Department may issue "cease and desist" and "clean-up" orders Failure to comply with such orders may result in temporary restraining order or injunction	Civil up to $10,000 per day of violation. Civil penalty credited to water quality control fund Criminal up to $12,500 if violator is negligent or reckless, up to $25,000 if violator is fully knowledgeable of the offense	Standards that may be promulgated under the Act's authority which could impact forest management include those for turbidity, temperature, and suspended solids At present, however, there are no standards for turbidity and suspended solids, and there is no program for regulation of nonpoint pollution sources. No forestry BMP's have been developed An assessment and management plan for nonpoint sources of pollution is currently under development No reference exists for excluding forest management operations from the point source pollution permit requirement as there is for irrigation return flow	Colorado Soil Conservation Act (35-70-101 to 121) established State Soil Conservation Board to conserve and protect water resources, including (1) the initiation of watershed planning to prevent flooding, and (2) the construction of structures to maintain soil stability and control erosion Colo. Rev Stat. 33-5-101 to 106 provides that no state agency may modify a watercourse without notification and a permit to insure protection of fishing streams Law does not operate to diminish existing water rights and does not apply to irrigation projects State Board of Agriculture has authority under Colo. Rev Stat 23-30-202 to "foster and promote" control of soil erosion on forest lands Pesticide Applicators' Act (Colo Rev Stat 35-10-101 to 125) provides that regulation of distribution, use, and application of pesticides is to involve balance of social utility and cost Colo Rev Stat 36-8-101 to 110 Regulates use of streams for floating logs to be used for any purpose, such use requires a permit from state engineer Colo Rev Stat 20-30-202 authorizes State Board of Forestry to "foster and promote" the control of soil erosion on forest lands Colo Rev Stat 23-30-301 states that policy objective of Colorado State Forest Service is to "conserve forest cover on watersheds"

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Idaho	Environmental Protection and Health Act of 1972 Idaho Code, Sec 39-101 to 118 Enacted 1947, amended 1973, 1979, 1980 supplemented 1987	Department of Health and Welfare, Environmental Protection Division	Department to promulgate and enforce regulations to enhance and preserve water quality Department authorized to recommend rules to Board of Health and Welfare regarding water pollution, and issue permits as prescribed by law Department also authorized to conduct investigations of violations of water quality standards Department may use compliance schedule to assure timely compliance with regulations Department authorized to implement water quality standards adopted by legislature	Civil penalty of $1,000 per day of violation or $10,000, whichever is greater, plus reimbursement of remedial costs incurred by the state Criminal willful or negligent violation is misdemeanor offense punishable by fine of up to $300 for each violation Each day a violation occurs is separate offense	Water quality standards acknowledge economic necessity of nonpoint pollution activities Management of nonpoint pollution designed to only reduce such pollution, state's position is that it cannot be eliminated without severe economic impact Generally, standards prohibit sediment in quantities which impair beneficial use of water Nonpoint sources of pollution specifically include silt, sand and rock resulting from silvicultural activities, or from log storage in water Silvicultural BMP's designed to protect water quality established in rules promulgated under Forest Practices Act (Idaho Code Sec. 38-1301 to 1312) These rules certified as approved water quality BMP's by Section 16 01 2300 05 of water quality standards issued by Department BMP's are mandatory for all forestry operations Department responsible for evaluation and modification of BMP's to insure protection of beneficial use of water Failure to meet water quality standards is *not* violation of law, but rather occasion for evaluating effectiveness of BMP's in protecting water quality Operators failing to follow BMP's are subject to compliance schedule and fine Injunctive and judicial relief are also available Where BMP's have not been developed, activity must be conducted to minimize detrimental impact to water	The Idaho Forest Practices Act (Idaho Code Sec 38-1301 to 1312) authorizes promulgation of rules to establish BMP's to protect water quality during all phases of forest management Drainage systems must control runoff waters from exposed surfaces. Slash and waste materials must not enter streams Streams to be protected by avoiding skidding and cable yarding in or through them, and by retaining vegetation to shade water and stabilize soil Chemical road construction, and reforestation BMP's are also designed to protect water quality BMP's last evaluated for effectiveness in protecting water quality in 1985 Results indicated that revision of Forest Practices Act rules was necessary Rules revised in 1986 and incorporated into 1987 draft of Forest Practices Water Quality Plan Feedback cycle for continuous proposal implementation, and evaluation of BMPs also included Violation of BMPs is misdemeanor Stream Channel Protection Act (Idaho Code 42-3801 to 3812) protects against deleterious alteration of stream channels Alterations impacting wildlife, aquatic life, recreation, or other facets of water quality require a permit from Department of Water Resources Act does not diminish existing water rights Failure to obtain permit (misdemeanor) may result in fine of $150 to $500 plus additional fine of up to $150 per day that violation continues Department has issued regulations governing stream channel alterations these are certified as approved BMP's which are mandatory for forestry operations Idaho Code Section 52-101 provides that unlawful obstruction of free passage or use in customary manner of any navigable lake, or river, stream canal or basin is considered public nuisance Idaho Code Sections 42-3601 to 3604 provide that Department of Lands is to cooperate with federal agencies in planning "works of improvement" (as per Watershed Protection and Flood Prevention Act of 1954, 16 USC Sec 1001-1009) to prevent erosion, floodwater, and sediment damage Idaho Code Sections 58-101 140 to 147 provides that encroachments into lakes regulated by Board of Land Commissioners Violators subject to fine ranging from $150 to $2500 Idaho Code Sections 58-401-405 provide that trees on state lands needed for conservation of irrigation water cannot be felled Nonmerchantable dead and down timber on state land not required for water conservation (soil stabilization) may be informally sold by Department of Lands as firewood Department of Water Resources must be given notice and opportunity to interpose objections prior to any timber sale
Kansas	Water Supply and Sewage Act Kansas Stat Ann. Ch 65 Art 16 Sec 1 to 71W Enacted 1897, amended 1909, 1923 1927 1967 1974, 1977	Department of Health and Environment	Department establishes water quality standards and issues permits for the discharge of sewage Department adopts rules and regulations for petroleum products storage, salt solution mining and laboratory certification where water sample analysis conducted Department may issue stop orders for violations	Criminal $2,500 to $25,000 fine per day of violation False statement up to $10,000 fine per day Civil up to $10 000 per day of violation Violators also liable for costs of restoration of damages	Definition of pollutant includes alterations which are harmful to plant, animal or aquatic life	Stream Obstruction Statutes (Kansas Stat Ann Ch 32 Art 1 Sec 2 Ch 82A Art 3 Sec 01 and Ch 24 Art 2 Sec 06) prohibit (1) obstructing the free passage of fish (2) willful obstruction or filling of any drain ditch or watercourse and (3) obstructions which change or diminish the course, current or cross-section of waters Floodplain Regulation Act (Ch 12 Art 2 Sec 06) grants local governments the authority to establish floodplain zones and restrict land use through ordinances and regulations Must be approved by Chief Engineer of Water Resources

Montana	Montana Water Quality Act Mont Code Ann Sec 75-5-101 to 75-5-641 Enacted 1967, amended 1971, 1973 1974, 1975, 1977, supplemented 1985	Department of Health and Environmental Sciences	Purpose of Act is to protect both quality and quantity of water Board of Health and Environmental Sciences authorized to adopt rules to achieve this objective, including classification of all waters and development of water quality standards Standards and classes not to allow water to be degraded below its existing state, unless justified by economic or social development Water quality standards need not exceed "natural" level of quality, where "natural" is defined as conditions or material present from water runoff over which man has no control or from developed land where all reasonable land, soil, and water conservation practices (BMP's) have been applied New sources of pollution require permit; existing quality level must be maintained	Civil violators subject to fine of up to $10,000 Each day of violation constitutes separate offense Criminal willful or negligent violators subject to fine of up to $25,000 per day of violation and up to one year in prison Subsequent convictions subject violators to $25,000 (maximum) fine and two years imprisonment	Water quality standards focus on "natural" quality of water Standards classify water by beneficial use, e g with respect to water classified for lower beneficial uses greater deviation is allowed from level of pollutants naturally occurring in the stream However land management activities must not generate pollutants in excess of natural levels, regardless of stream class Forestry BMP's developed by Department of State Lands include guidelines on road construction harvesting reforestation, and fire suppression Under Memorandum of Understanding, both private and public forest managers have agreed to abide by established BMP's Runoff and sedimentation acceptable if reasonable conservation practices (BMP's) are applied and beneficial uses of water are maintained Exceptions to nondegradation rules allowed based on need for social and economic development	Mont Code Sec 76-13-101 to 601 provide for protection and conservation of forest, water, and range resources including regulation of streamflow and prevention of soil erosion Mont Code Sec. 75-6-101 to 13 provide for the protection of public water supplies Prohibit building logging camps or roads near public water supplies and industrial waste discharge from development of natural resources into such waters The Natural Streambed and Land Preservation Act of 1975 (Mont Code Sec 75-7-101 to 124) prohibits unauthorized alteration of streambeds Board of Natural Resources and Conservation authorized to issue regulations governing streambed alterations Existing water rights are preserved Failure to obtain permit may subject violator to fine of $25 to $500 per day plus remedial costs Mont Code Section 27-30-101 declares any obstruction or injury of navigable lake river bay stream, or canal to be a nuisance Mont Code Sec 75-7-201 to 217 Permit required for alteration of lakeshores
Nebraska	Environmental Protection Act Rev Stat Neb T 81 Sec 1501 to 15,127 Enacted 1971, amended 12 times, 1972 to 1987	Department of Environmental Control and Environmental Control Council	Council adopts rules and regulations and sets standards for land, air and water quality Department enforces provisions of the Act and Council rules and regulations Department issues permits and may order violator to take corrective action Department may grant variances Act addresses litter control and disposal	Criminal up to $5,000 fine per day of violation and/or six months imprisonment Civil up to $5,000 per day of violation Violators responsible for pollution resulting in the death of fish or wildlife are liable for compensation to state for restocking fish or replenishing wildlife Prosecutions civil in nature except where clear criminal intent or knowing violation takes place	Legislative authority sufficiently broad to include nonpoint sources of pollution Purpose of Act includes the protection of fish and other aquatic life	Floodplain Management Act (Rev Stat Neb Sec 31-1001 to 31-1031) requires a permit prior to obstruction of any watercourse or floodplain Nebraska Natural Resource Commission develops and adopts minimum standards for incorporation into local governmental regulations If not adopted by local governments state regulations are automatically effective Littering of Waters Act (Sec 37-516) prohibits placing litter trash lumber or any material injurious to aquatic life in or near waters Fishway Through Dams Act (Sec 37-406) requires owner of dam or other obstructions across watercourse to insure flow of water sufficient for support of aquatic life Stream Obstruction Statute (Sec 455 160) prohibits and deems a nuisance any obstruction diversion filling up, ditching or draining any watercourse which has been prohibited by a resolution of the drainage district Erosion and Sediment Control Law (Sec 2-4601 to 2-4613) requires natural resource districts to adopt a program for implementation of state's erosion and sediment control plan, including soil loss limits Regulations must be at least as stringent as state's Silvicultural activities are regulated under the law
Nevada	Nevada Water Pollution Control Law Nev Rev Stat Sec 445 131 to 445 354 Enacted 1973 amended 1977 1979, 1981, 1985	Division of Environmental Protection within Department of Conservation and Natural Resources	Purpose of Act is to maintain quality of water consistent with beneficial uses and encourage use of pollution control methods State Environmental Commission authorized to adopt water quality standards and regulations to control nonpoint source pollution Standards must protect designated beneficial use of each stream segment Standards proposed may vary from those based on recognized criteria if circumstances justify If existing water quality exceeds applicable standard water quality must be maintained at the higher existing level	Director may issue corrective order to remedy diffuse source of pollution, but no civil or criminal penalty other than injunctive relief or temporary restraining order may be imposed Diffuse source violators are excepted from monetary penalties	Commission authorized to regulate diffuse (non-point) sources of pollution, including those emanating from silvicultural operations, in order to enforce non-degradation policy of water quality standards Diffuse source discharges must be controlled by reasonable methods based on particular location and economic capability of project or development Silvicultural activities exempt from discharge permits unless certified as significant contributor to pollution Municipalities charged with administering pollution control regulations promulgated by Commission	Nev Rev Stat Sec 472 043 provides for the maintenance of vegetative cover on forest and watershed land in order to conserve water and soil State Forester Firewarden is authorized to enter into contracts and take other measures designed to meet this objective Nevada Forest Practices Act of 1955 (Nev Rev Stat Sec 528 010 to 528 120) requires issuance of a permit prior to any logging or cutting operation Permit mandates submission of a logging plan including proposed road construction specifications and erosion control measures Tractor logging on slopes in excess of 30 percent gradient requires a variance from State Forester Firewarden Erodibility of soil must be considered in variance application Variance is also required to harvest trees.

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
					Forestry operations must utilize BMP's developed by State Board of Forestry under state Forest Practice Act, for non-point pollution control Accepted forestry BMP's focus on five planning criteria for control of runoff and sedimentation resulting from forest management activities silvicultural treatments, logging methods, erosion control and road-building, hazard reduction, and forest protection	operate equipment or construct logging roads within 200 feet of a body of water Erosion control is primary objective Nevada Forest Practices Act of 1955 is also reflected in numerous management specifications to prevent runoff and sedimentation State Forester Firewarden authorized to adopt BMP's under the Act As discussed above, regulations under Water Pollution Control Law require that selected BMP's, depending on particular situation, be utilized in conjunction with forestry operations in order to control non-point water pollution Nev Rev Stat Sec 503 430 Forest products processing waste such as sawdust, shavings, etc introduced into water at any time in a manner deleterious to fish is a misdemeanor offense Nev Rev Stat Sec 445 080 to 120 concern the protection of Lake Tahoe Permit required for alteration of shoreline Nev Rev. Stat Sec 445 100 authorizes State Environmental Commission to adopt regulations concerning Lake Tahoe watershed Any timber operations within Tahoe Basin must have approval of Tahoe Regional Planning Commission Nev Rev. Stat Sec 244 365 Boards of County Commissioners authorized to bring suit against any violator who deposits sawdust in any river or stream Nev Rev Stat Sec 535 100 Lumber mills prohibited from obstructing natural stream flow.
New Mexico	Water Quality Act N M Stat Ann Sec 74-6-1 to 13 Enacted 1978, amended 1985, supplemented 1986	Water Quality Control Commission (composed of officials from relevant state resource management agencies) Lead agency is Department of Health and Environment	Commission authorized to adopt comprehensive water quality standards, regulations, and classifications Fixed-term, individual variances can be granted if compliance with regulations is unduly burdensome Commission may require permit, issued by constituent agencies charged with administration of standards and regulations No regulation or water quality standard is adopted until after public hearing Persons affected by regulations may petition court for relief Court may strike regulations which are illegal, arbitrary, or not supported by evidence as to their purpose Commission may seek injunctive relief Commission *not* authorized to regulate pollution confined entirely within property on which it occurs	Civil penalties not to exceed $1,000 for each violation Each day violation occurs is separate offense Violators also liable for reasonable remedial costs Violation of permit regulations is misdemeanor punishable by fine of $300 to $10,000 per day and one year imprisonment Civil penalty for permit violation may not exceed $5,000 per day.	Water quality standards as such are unenforceable, but are primarily used as guidelines in evaluating discharge permits The standards primarily affecting forest management activities are those protecting high quality cold water fisheries and domestic water supplies These standards are very stringent Water quality regulations prohibit disposal of refuse in a natural watercourse. Voluntary guidelines (BMP's) concerning most aspects of forest management have been certified by Water Quality Control Commission. State water quality management plan requires evaluation of effectiveness of voluntary BMP's in protecting water quality. Evaluation was due at end of 1987, after three year trial period	Forest Conservation Act (N M Stat Ann Sec 68-2-1 to 25) authorizes Forestry Division of Natural Resources Department to enforce all laws and regulations concerning logging and forest land conservation in order to maintain water quality N M Stat Ann Sec 30-8-2 Water pollution defined and declared a public nuisance, punishable as a misdemeanor N M Stat Ann. Sec 17-4-29 requires persons floating logs, timber, or other forest products to deposit 1000 trout fingerlings annually into fisheries specified by Department of Game and Fish Violation of statute is a misdemeanor, but statute is rarely if ever enforced N M Stat Ann Sec 72-10-2 authorizes commissioners elected from community to bring suit against any person who obstructs community spring, dam, or breakwater

North Dakota	Water Pollution Control Law N Dak Century Code, Sec 61-28-01 to 61-28-06 Enacted 1967; amendec 1969, 1971, 1973, 1975 1983	Department of Health and Water Pollution Control Board	Department authorized to adopt rules and regulations for pollution control and establish water quality standards Department issues permits and orders Department may seek injunction to stop violations	Criminal up to $25,000 fine per day of violation and/or one year imprisonment Penalty is doubled for second offense Civil: up to $10,000 fine per day of violation	Definition of pollution sufficiently broad to include nonpoint sources Rock, sand and agricultural wastes are potential pollutants	Soil Conservation District Law (N Dak. Century Code, Sec 4-22-01 to 4-22-51) Land use regulations, including those for forestation and reforestation, may be adopted upon approval of two-thirds of the voters in the district through referendum Obstruction of Watercourse Statute (Sec 61-01-07) prohibits obstruction of or diversion of water from any ditch, drain or watercourse. Water Resource District Law (Sec. 61-16 1-09 to 61-16 1-52). District boards are authorized to adopt rules and regulations to prevent pollution or other misuse of water resources, streams or bodies of water Permit required for draining ponds, sloughs, or lakes over 80 acres in size State engineer empowered to take action to rehabilitate damages. Floodplain Management Act (Sec 61-16.2-01 to 61-16.2-13) requires communities to adopt ordinances in compliance with national flood insurance program. Encourages communities to adopt and enforce floodplain management ordinances Activities which increase base flood level prohibited Little Missouri Scenic River Act (Sec 61-29-01 to 61-29-06). Little Missouri River Commission empowered to promulgate management policies. Prohibits diversion of water for purposes other than agriculture, recreation, or dredging on Missouri River or tributaries of river.
South Dakota	Water Pollution Control Act S Dak Code Laws Ch 34A-2 Sec 1 to 99 Enacted 1935 amended 15 times, 1939 to 1987	Department of Water and Natural Resources under authority of Water Management Board	Water Management Board authorized to issue water quality and effluent standards, classify waters as to beneficial uses, and establish rules for issuance of permits Department issues permits and enforces permit conditions, and may issue orders for prevention, abatement, or control of pollution Board may initiate court action against continuation of a violation or failure to comply with an emergency order	Violations Class 1 misdemeanor Criminal up to $10,000 fine per day of violation and up to one years imprisonment. Civil up to $10,000 per day of violation	Definition of pollution includes alterations which exceed water quality standards for temperature or turbidity or which are likely to be harmful to birds, fish or other aquatic life Potential pollutants include agricultural wastes, rock, sand and dredged spoil Act infers it is applicable to non-point source discharges (Sec 34A-2-39 1)	Restriction on Riparian Use Act (S Dak Code Laws Ch 46 Sec 5-1) prohibits polluting of natural springs or streams and activities which will alter their natural flow Ch 46 Sec 5-1 1 prohibits obstruction of navigable waters Scenic Rivers Act (Ch 46A-1-15 to 16) authorizes the Board of Water and Natural Resources to designate certain rivers or sections of rivers as wild, scenic, or recreational After designation, no development shall occur which alters natural and scenic beauty Act establishing Watershed Districts (Ch. 46A-14 Sec. 1 to 92) Watershed districts may be established to regulate the flow of streams, diversion of watercourses, and for imposition of preventative or remedial measures for control of soil erosion and siltation of watercourses Soil Erosion and Sediment Damage Law (Ch 38-8A Sec. 1 to 28) Conservation district supervisors required to develop standards for control of erosion and sediment resulting from land disturbing activities Political subdivisions responsible for granting permits Process must insure activities are in compliance with standards Some activities require submission of a plan Agricultural activities, including forestry, are exempt provided standards are met. Protection of Fishing Waters Act (Sec 41-13-1 to 41-13-11) prohibits the placement of sawdust, refuse or sedimentary materials into waters supporting game fish or to deposit it in such a way as to be carried into waters by natural causes

Table C.3—Significant features of water quality legislation in the Rocky Mountain Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Utah	Utah Water Pollution Control Act Utah Code Ann Sec 26-11-1 to 20 Enacted 1953, amended 1981, 1982 1987, supplemented 1987	Water Pollution Control Committee (composed of Director of Department of Health and eight members appointed by governor), under Department of Health	Committee to develop programs to prevent control, and abate new and existing water pollution Committee may promulgate water quality and effluent standards, and classifications based on "reasonable uses" Discharge of any pollutant into water which menaces public health or impairs beneficial uses of waters is public nuisance Governor may identify areas with water quality problems Committee authorized to classify waters according to reasonable present and future use, and to issue water quality standards for each classification Public hearing required prior to promulgation of water quality standards or classes Committee may seek injunctive relief or compliance order	Civil up to $10,000 per day, or up to $25,000 per day for willful or grossly negligent violation of Secs 26-11-8(2) and 26-11-14 Subsequent violations maximum penalty of $50 000 per day	Forest lands generally full into "Class 1 and 2" lands for the protection of domestic, recreational and other beneficial water uses Turbidity and temperature standards are the ones most relevant to forest management Discharges which do not meet use classification standards are prohibited Water quality standards require existing quality not be degraded, unless reduction justified by economic or social development Water for human consumption protected by higher standards Diffuse sources of pollution (non-point) into such waters must be controlled by either BMP's or regulatory programs No statewide system of forestry BMP's exists, but certain local BMP's are certified under state 208 water quality plan Voluntary inclusion of BMP's in timber sale contracts has been effective in meeting water quality standards State-wide certification of forestry BMP's is underway	Utah Code Ann Sec 23-15-6 prohibits pollution of water crucial to wildlife including aquatic life Utah Code Ann Sec 76-10-203 prohibits obstruction of irrigation watergates by floating logs or timber (antiquated) Utah Code Ann Sec 17-8-5 5 Counties may issue ordinances for protection of flood plains and channels Utah Code Ann Sec 65-1-75 authorizes State Land Board to take necessary measures to prevent damaging floods and conserve state's natural resources Statute recognizes role of improper timber management in flooding and authorizes Board to take steps to prevent flooding resulting from poor timber management Utah Code Ann Sec 63-11-17 5 authorizes Division of Parks and Recreation to regulate development on lands within their jurisdiction Division may impose regulations which are stricter than municipal ordinances
Wyoming	Wyoming Environmental Quality Act (Wyo Stat Sec 35-11-101 to 1104 Enacted 1973, amended 1977, supplemented 1987	Environmental Quality Department	Discharge of any pollutant into water or alteration of physical, chemical or biological properties of water is prohibited, except by permit Division of Water Quality may develop regulations and water quality standards, including effluent limitations, and classify surface waters	None specified	Water quality standards serve as indicator as to whether BMP's should be developed Violation of water quality standards by a nonpoint source is sufficient justification for development of BMP's Water quality indicators relevant to forestry include water temperature and turbidity To date, only turbidity has been used to limit forestry activities Currently, no BMP's established for harvesting activities Forest Management activities considered to have only minor impact on water quality in state However, voluntary silvicultural BMP's are currently under development	Wyo Stat Sec 11-16-101 to 132 establish soil conservation districts to promote soil conserving practices Wyo Stat Sec 35-4-202 Sawmill owners who dump sawdust or chemical wastes into *natural* stream or lake thereby killing fish or rendering water impure are guilty of misdemeanor. Violation punishable by fine of $50 to $100 or imprisonment from one to six months Each day of violation is separate offense Wyo Stat Sec 41-5-108 requires permit for floating logs in streams or rivers (antiquated) Wyo Stat Sec 41-8-101 to 126 create watershed improvement districts as subdistricts of soil conservation districts Each improvement district must lie within a watershed Improvement districts authorized to develop local watershed protection programs and ordinances, which could impact silvicultural activities

Table C.4—Significant features of water quality legislation in the Pacific Coast Region

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Alaska	Alaska Stat Sec 46 03 050 to 130, 320 to 800, 850. Enacted 1969, amended 1977, 1978, 1980, 1981, 1982, supplemented 1986	Department of Environmental Conservation	Law provides general prohibition of water, land and air pollution which has withstood constitutional challenge Department may propose water quality standards and determine qualities and properties of water which indicate a polluted condition After public hearings, Department authorized to develop water quality standards, classify waters as to minimum quality, or both A short term variance from standards is available if economic or social development justify water quality reduction Department also authorized to regulate use of pesticides Activities impairing domestic water quality are prohibited as a nuisance. Department may issue compliance order for violation of water quality standards	Civil penalty for initial violation ranges from $500 to $100,000 and up to $5,000 for each day violation continues Penalty determined by degree of environmental damage, investigation and litigation costs, and economic savings realized by the violator Violator is also liable for cost of restoring environment to original condition Court may grant temporary or preliminary equitable relief Violations punishable as misdemeanors Each day a violation occurs is a separate offense	Department has created water quality "use classes" which specify the degree of degradation not to be exceeded by human activity Forest management is impacted by turbidity and sedimentation water quality parameters and pesticide regulation Water quality standards consider social and economic factors as well as scientific criteria for protection of environment Voluntary BMP's (in conjunction with Alaska Stat 41 17 010) regulate forest management activities to meet requirements of water quality "use classes" Since BMP's are voluntary, standards may be enforced whether or not BMP's are being used	Alaska Stat Sec 41 17 010 to 950 established Division of Forestry within Department of Natural Resources to execute forest management standards, policies, and guidelines Department of Natural Resources may develop regulations for control of nonpoint sources of pollution, in cooperation with Department of Environmental Conservation Scope of regulations includes all aspects of forest management with recognition of environmentally sensitive areas (e g stream buffer zone for eagle habitat) and BMP's As voluntary guidelines, BMP's are not site-specific, but must be adapted to protect the water resources of the area Department of Natural Resources is charged with review of proposed forest management plans and subsequent inspections to ensure compliance with water pollution regulations Departments cooperate to evaluate plans to use broadcast chemicals Violators are liable for civil fine up to $10,000, depending upon the amount of environmental damage, economic savings reaped by the violator, degree of intent or negligence, and past violations Department of Natural Resources may issue a temporary stop order if violation is likely to result in irreversible harm Department of Natural Resources may not usurp the statutory authority of other state agencies, unless authorized by Alaska Coastal Management Act or by the Department of Environmental Conservation Alaska Stat Sec 16 05 870 to 900 provides that Department of Fish and Game shall identify specific water bodies important to spawning, rearing and migration of anadromous fish and review plans to use such waters (e g log dragging) Use of these waters without Departmental review and approval is a misdemeanor punishable by a $1,000 (maximum) fine Violator is liable for restoration costs and other penalties imposed by the court Alaska Stat Sec 16 10 010 prohibits the dumping of waste such as tree limbs or foliage, stumps, sawdust, planar shavings, earth or other debris into salmon spawning streams in support of the policies underlying Sec 16 05 870 Permit for obstruction of such waters required by Department of Environmental Conservation Violation of Sec 16 10 010 is a misdemeanor punishable by a fine of $100 to $500 Alaska Stat Sec 16 20 185, 16 20 240 to 260 requires Department of Fish and Game to protect habitat of endangered species Board of Fisheries and the Board of Game authorized to adopt regulations governing the taking of fish and game from critical habitat areas Before land in these areas may be developed, leased or otherwise disposed" of the Department of Fish and Game must be notified Written approval of the plans for disposal of the land from the Department may be required 5 AAC 95 010 to 990, regulations for management activities on game refuges and critical habitat areas, require a permit for such activities and mitigation of adverse environmental impacts 6 AAC 80 100 incorporates Alaska Stat 41 17 into Alaska Coastal Management Program Attorney General's opinion (J-66-224-79) indicates that the Department of Natural Resources's regulation of forest management practices preempts only the forest management standards of Alaska Stat 46 40 (Coastal Zone Management Act), and not the entire act

Table C.4—Significant features of water quality legislation in the Pacific Coast Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
California	Porter-Cologne Water Quality Control Act, California Water Code California Stat Sec 13000 to 13361 Enacted 1969, effective 1970 Amended 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1982, 1984, 1985, 1986	Water Resources Control Board	Authorizes Board to formulate water quality policy and to promulgate regulations for protecting water quality Cities and counties may also adopt regulations, which must be consistent with those issued by Board Identifies nine water quality regions and authorizes regional board for each Provides for State Water Quality Control Plan, which is to include "basin" plans formulated by each regional board Requires regional boards to establish water quality standards to protect beneficial uses Authorizes regional boards to prescribe requirements for any discharge (essentially a permit program) If requirements have been prescribed, a waste discharge report must be filed with the Board	Civil penalty for failure to file waste discharge reports and/or for deviations from discharge requirements ranges from $1,000 to $5,000 fine per day of violation, depending upon whether imposed administratively or judicially Regional boards may issue cease and desist, and clean-up and abatement orders Civil penalty for failure to adhere to cease and desist orders up to $6,000 per day of violation If clean-up and abatement orders are ignored, state may take remedial action and the cost is imposed upon the violator	Implications for forestry begin at the state level with the Water Resources Control Board The Board has adopted a nondegradation policy which states that whenever existing water quality is better than that established by policy, such existing high quality will be maintained unless it can be demonstrated that any change will be consistent with maximum benefit to the people of the state, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed by policy Board has also required that each regional plan contain prohibitions against discharge of soil, silt, bark, slash, sawdust, or other organic or earthen material from logging operations into any stream or watercourse in quantities deleterious to fish, wildlife, or other beneficial uses, or against the placing of such materials at locations where they could pass into any stream or watercourse The nondegradation policy and these two non-point pollution prohibitions summarize the Board's general position regarding protection of beneficial water uses from the adverse effects of timber harvesting and associated activities Within this general framework, the nine regional boards carry the primary responsibility for on-the-ground regulation of water quality in accordance with their individual "basin" plans. With respect to forestry operations, these plans address the sources of pollution in each basin from timber operations, the types of impacts that such pollution may have on beneficial uses, and the water quality standards and objectives needed to protect water quality and beneficial uses Regulation is effected through the water quality related rules promulgated under the state's forest practice act (Z'berg-Nejedly Forest Practice Act of 1973, Calif.Stat Sec 4511–4621) These rules are minimum protection standards applicable to all commercial timber operations on non-federal timberlands. The current rules interact with the State Water Code by defining the beneficial uses of water to include those uses listed in the Water Code. With respect to non-point pollution, the rules cover silvicultural methods, harvesting practices and erosion control, water-	Section 30417 of the 1976 California Coastal Act authorizes the Coastal Commission to identify special treatment areas within the coastal zone and to recommend forestry operation rules to the Board of Forestry which are adequate to protect the natural and scenic qualities of these areas These rules impose higher than average standards for forestry activities within these areas California Fish and Game Code (California Stat Sec 1603, 1606) provides that any person who obstructs or diverts any water body of those designated by the Department of Fish and Game must first notify the Department and follow procedures recommended by it, submitting a timber harvesting plan as required by the Forest Practice Act will constitute sufficient notice California Statutes Section 5650 prohibits deposit of any slabs, sawdust, shaving, etc into any waters of the state, with violation constituting a misdemeanor California Statutes Section 5093.68 essentially imposes the same requirements as do the forest practice rules on "special treatment areas" designated under the state Wild and Scenic River Act.

					course and lake protection, and construction of logging roads and landings. The Forest Practice Act provides that timber operations will be exempt from the Water Code's waste discharge requirements if the forest practice rules promulgated under the Act are certified by the federal Environmental Protection Agency (EPA) as constituting best management practices (BMP's) for silviculture pursuant to Section 208 of the Federal Water Pollution Control Act. Such certification is presently pending. Until it is effective, the regional boards can impose specific waste discharge requirements on timber operations. As a practical matter, however, they seldom do.	
Hawaii	Basic Water Pollution Statute Hawaii Rev. Stat Ch 342-1 to 20, 31-35 Enacted 1972, amended 1973, 1980, 1982, 1984, 1985 State Water Code. Hawaii Rev Stat Ch 175C-1 to 101 Enacted 1987	Department of Health	*Water Pollution Statute*. Department charged with prevention, control and abatement of water pollution Department may establish water quality and effluent standards, and promulgate regulations to control pollution according to local conditions Pollution discharge into state waters controlled by permit Department may also approve variances, issue "cease and desist" orders, and initiate court action for injunctive relief *State Water Code* authorizes Commission on Water Resource Management to develop statewide water management areas and instream waterflow standards Commission authorized to promulgate instream flow standards on stream-by-stream basis Water management areas control water use in areas where resource is threatened Instream flow standards describe waterflow necessary to protect variable interests in streams, including recreational, wildlife, and fishery interests. Commission must hold public hearing for discussion of proposed standards Permit required to alter stream channels Administrative rules implementing State Water Code currently under development.	Civil: Department may initiate civil action to recover penalty. Criminal: for willful violation of any rule or regulation violator may be fined from $2,500 to $25,000 per day and may be imprisoned for up to one year.	Specifically designated pollutants include sediment, soil, and sand. Agricultural wastes also designated as potential pollutants Established Water quality criteria relevant to forest management include those related to detrimental alteration of water turbidity or temperature	Hawaii Pesticides Law (Hawaii Rev. Stat Ch. 149A-31 to 33) regulates the application of pesticides and provides for the suspension or cancellation of pesticide use if chemical residues are detected in drinking water, or under other conditions of "unreasonable adverse [environmental] effects". Hawaii Rev Stat Ch. 180C-2 County governments may enact ordinances for erosion and sediment control, primarily from urban sources. Hawaii Rev Stat Ch 183-1 to 45 Department of Natural Resources responsible for protecting, extending, and increasing forest reserves for watershed management Forest and water zones established in each county Zones encourage highest economic use of resource consonant with water conservation. In subzones within reserve zones, Department may specify land use—including commercial timber growing. Regulations may prohibit unlimited cutting of forest growth or forestry practices detrimental to water conservation. Hawaii Rev. Stat Ch 205A. Controls on development of coastal areas do not restrict planting, cultivation, and harvesting of trees or other forest products, unless such activities have a cumulative negative impact on water resources. Under such conditions forest management is "development" and subject to permit requirement In issuing permits, County Planning Commission must seek to minimize impact on water quality Hawaii Rev Stat Ch 181 prohibits discharge of poisonous or noxious effluent into streams or shorewaters Specifies guidelines for reclamation Hawaii Rev. Stat Ch 339 prohibits dumping of litter into water. Definition of "litter" does not include nonpoint pollutants

Table C.4—Significant features of water quality legislation in the Pacific Coast Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
Oregon	Ore Rev Stat Sec 468 700 to 468 778 Enacted 1953, amended numerous times	Department of Environmental Quality	It is public policy to protect and improve water quality, and to prevent or abate pollution Polluting water is not a reasonable or natural use of such waters and is prohibited, as is discharge of wastes which reduces quality Environmental Quality Commission authorized to develop water quality standards based upon specifically enumerated quality criteria which are specified in statute Persons who injure or destroy fish and wildlife or habitat are strictly liable for restoration costs	Civil penalty of up to $500 per day of violation Penalties for specified violations such as discharge permit violation up to $10,000 per day of violation	Department of Environmental Quality has issued comprehensive water quality regulations These include general guidelines and specific standards which apply to each individual drainage basin Guidelines applicable to forestry address antidegradation, restrictions on log handling in public waters, and forest management activities The latter are directed to be conducted in accordance with the Oregon Forest Practices Act (OFPA) Specific standards include water quality characteristics such as turbidity and temperature Primary protection of water quality relative to forest management is thus derived from rules (BMP's) promulgated under the Forest Practices Act These control impact of forest practices on water quality for three regions within state. Rules establish minimum standards for chemical use, slash disposal, reforestation, road construction, and harvesting The rules have been certified by the federal Environmental Protection Agency (EPA) as acceptable BMP's for purposes of the Federal Water Pollution Control Act	Oregon Forest Practices Act (Ore Rev Stat Sec 527 610 to 527 730) authorizes promulgation of rules (BMP's) regarding forest management activities and protection of water quality Rules are designed to assure sustained yields of timber while protecting water, air, and soil quality State Board of Forestry authorized to adopt rules as minimum standards for forestry practices Rules must maintain water, air and soil quality, and provide for protection of fisheries, wildlife habitat and sensitive ecological sites Board must resolve any conflicts between rules and special management requirements of sensitive areas Forest practice activities must conform to water quality standards Rules recently changed to require a written management plan if harvesting is to occur within 100 feet of a Class I stream or within 300 feet of a site inventoried for threatened and endangered species Evaluation of OFPA indicates that forestry rules have been "moderately effective mechanism for improving water quality in forest streams" Violation of OFPA is a misdemeanor Each day of violation is a separate offense Forest Practice Rules (Ore Admin Rules 629-24-101 to 646) include general rules and specific standards for each of 3 regions General rules require notification of the State Forestry Division prior to conducting forest management activities and prior approval of stream channel alterations General rules also provide for stream classification system, criteria for riparian area boundaries, limits on use of chemicals, and slash disposal guidelines Regional rules cover all aspects of forest management A provision for the protection of waters requires landowners to maintain riparian areas along the boundaries of Class I water Ore Rev Stat Sec 390 805 to 390 925 establish Oregon Scenic Waterways System in which recreation fish and wildlife interests are of paramount importance Department of Transportation authorized to adopt rules regarding management of lands adjacent to scenic waterways. Rules restrict road construction and require timber harvests be conducted to maintain aesthetic value of water Department must be given notice prior to timber harvest for evaluation of impact on scenic water Department may attempt to alter timber harvest plan or acquire land by purchase, gift, or scenic easement Ore Admin Rules 736-40-005 to 095 require timber harvests to conform to preservation of scenic beauty of waterway Department of Transportation management of "adjacent lands" includes all land within 1/4 mile of streambank, excluding lands which do not affect the view from scenic waterway Management prescribed by Department is determined by subjective evaluation Ore. Rev Stat Sec 541 605 to 695 require permit for removal of any material from streambank, with exceptions for forestry activities in compliance with Forest Practice Rules Ore Rev Stat Sec 549 400 prohibits obstruction or pollution of any waterway or drainage improvement

Washington	Washington Water Pollution Control Act Wash Rev Code Ann Sec 90 48 010 to 90 48 910 Enacted 1971, amended 1973, 1975, 1983, 1985	Department of Ecology	It is state policy to insure water purity for all beneficial uses Act creates Water Pollution Control Commission which is authorized to develop regulations and water quality standards Any discharge which pollutes waters is prohibited State may bring action against violators for costs of restoring environment Department has sole responsibility for and authority over water quality standards and regulation of nonpoint sources of pollution in state Regulations promulgated under state's Forest Practices Law must meet water quality standards and satisfy water pollution control laws Department required to monitor water quality and has final authority to modify forest practice regulations as they pertain to water quality Permit requirements and penalties imposed by Act do *not* apply to forestry activities that are in compliance with Forest Practices Act Forest Practices Act and corresponding regulations must also satisfy requirements of Federal Water Pollution Control Act (33 USCA Sec 1288, 1289, 1315)	Criminal, violations punishable by fine of up to $10,000 plus litigation costs Violator may be imprisoned for up to a year Each day of violation is separate offense Civil penalty of up to $10,000 per day of violation	Department of Ecology has developed separate set of standards pertaining specifically to forestry operations However, there is no criminal or civil penalty for degradation of water quality by practices which are in compliance with regulations issued under Forest Practices Act Department of Ecology has not developed a forestry non-point pollution control program of its own However, BMP's and regulations issued under Forest Practices Act are subject to modification by Department if they fail to meet water quality standards Water quality characteristics relevant to forestry include those for temperature and turbidity Forest Practices Act regulations have been certified as meeting requirements of Section 208 of Federal Water Pollution Control Act	Forest Practices Act (Wash Rev Code Ann Sec 76 09 010 to 76 09 950) authorizes forest practices regulations which comply with Section 208 of Federal Clean Water Act concerning nonpoint pollution control Department of Ecology may propose forest practices regulation relating to water quality in cooperation with Forest Practices Board, Department has final authority Recent legislative changes authorize Department of Natural Resources to prepare hazard reduction plan for sites where soil erosion poses significant danger to public resources Riparian zones protected by requiring some trees be left standing Department of Natural Resources may issue "stop work" order, or a "notice to comply" to violators Department of Ecology may enforce compliance with Act 6 if Department of Natural Resources fails to do so Violators may be subject to a fine of $500 per day of violation plus an additional penalty of $100 to $1,000 and up to one year imprisonment Statutory restrictions on authority of local governments to promulgate their own forest practice rules (Sec 76 09 240(4)) held invalid in *Weyerhauser v King County (91 Wash 2d 721, 1979)* Forest Practices Rules and Regulations (Wash Admin Code Ch 173-202-010 to 020) Regulations pertaining to water quality protection are individually adopted by Forest Practices Board and Department of Ecology after the agencies have reached agreement Water quality provisions are found in forest practices regulations concerning timber harvesting, reforestation, road construction and chemical application Evaluation of regulations in 1980 indicated that impact of forestry on water quality is relatively low overall, but impact from individual operations was severe in some cases Recently proposed amendments are the product of broad consensus among government agencies, public interest groups, and forest products industry Primary goal is to maintain viable forest industry and protect quality of natural resources Amendments accepted "in concept" by Forest Practices Board include (1) creation of riparian management zones, (2) limitations on road construction and timber harvests in riparian zones and (3) further restrictions on application of silvicultural chemicals to protect water quality Wash Rev Code Ann Sec 7 48 010 Obstruction of stream channels used for rafting logs, timber, or lumber is a nuisance Wash Rev Code Ann Sec 9 66 010 Unlawfully befouling obstructing or interfering with a lake navigable river bay, stream, canal or basin is a public nuisance Wash Rev

Table C.4—Significant features of water quality legislation in the Pacific Coast Region—Continued

State	Statute and reference	Administering agency	Basic provisions	Penalties for violations	Significance for forest management	Related statutes
						Code Ann Sec 75 20 050 to 140 concern protection of streambeds from impacts by hydraulic projects Department of Fisheries authorized to evaluate projects and deny approval or require modification to protect fisheries Violation of Act is a gross misdemeanor and a public nuisance Civil penalty of up to $100 per day of violation may be imposed Recently proposed amendments suggest giving Department of Fisheries or Department of Game discretion on penalty imposed either fine, or gross misdemeanor charge punishable by fine and imprisonment Wash Rev Code Ann Sec 76 32 040 This 19th century statute authorizes timber companies to channelize streams, remove obstacles, etc Such improvement projects may not impede or obstruct stream outlets or interfere with use of such streams Wash Rev Code Ann Sec 76 42 030 to 070 authorize Department of Natural Resources to remove wood debris from navigable waters Disposal of wood debris into such waters is prohibited Wash Rev Code Ann Sec 79 01 128 Department of Natural Resources may modify management practices on public lands within municipal watersheds so that water quality exceeds state standards Municipality must reimburse Department for additional management costs incurred *Fransen v State Board of Natural Resources* (66 Wash 2d 672, 1965) held that state may not *sell* its forest lands to achieve statutory objective Wash Rev Code Ann Sec 79 72 010 to 900 authorize Department of Parks and Recreation to take measures to protect scenic rivers To date Department has relied upon existing regulations to protect scenic rivers' water quality However, conservation plan with possible regulatory standards is under development Wash Rev Code Ann 88 28 050 imposes a fine of up to $200 per day upon persons who obstruct navigable streams, channels, or rivers, excluding booms to secure floating logs Wash Rev Code Ann Sec 90 28 150 provides for stream improvements (clearing debris or straightening of channel) when necessary for logging "Shoreline Management Act of 1971 (Wash Rev Code Ann Sec 90 58 010 to 930) is designed to protect natural character, ecology, and public access to shorelines, including banks of streams and lakes Act requires permit for development along shorelines, including logging road construction Harvesting within 200 feet of identified shorelines is limited to selective cuts of no more than 30 percent of merchantable volume Other" harvesting methods may be used if selective cut is ecologically detrimental, or for approved land development Challenge to statutory limitation on road construction defeated (*Weyerhauser Co v King* 91 Wash 2d 721, 1979)

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
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Fort Collins,
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**General Technical
Report RM-178**

An Analysis of the Wildlife and Fish Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Curtis H. Flather
Thomas W. Hoekstra

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
General Technical Report RM-178

September 1989

An Analysis of the Wildlife and Fish Situation in the United States: 1989–2040

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Acknowledgments

Many individuals from the Forest Service, other federal agencies, state agencies, universities, and conservation groups contributed to this document. Individuals that assisted in compiling information for national forest lands were: Robert Nelson, Jack Capp, Mike Dombeck, Robert Randall, Kirk Horn, Alan Christensen, Glen Hetzel, Dale Wills, William Zeedyk, Richard Wadleigh, William Burbridge, Ronald Burraychak, Randall Long, John Borrecco, Hugh Black, Philip Lee, Jerry McIlwain, Tom Darden, Gordon Sloane, Bruce Hronek, and Donald Hagar. Assistance in compiling information on wildlife and fish resources from the Bureau of Land Management was provided by J. David Almand and Raymond Boyd. Other federal cooperators included: Warren Fisher, John Charbaneau, William Gill, Ronald Lambertson, John Tautin, Terry Cacek, Bill Wilen—Fish and Wildlife Service; Steve Koplin—National Marine Fisheries Service; Steve Brady, Billy Teels—Soil Conservation Service.

The following were instrumental in compiling state wildlife and fish statistics: AL—Charles Kelley, Jim Davis, Barry Smith; AK—W. Lewis Pamplin, Bruce Baker; AZ—Bud Bristow, Duane Shroufe, Roger Sorenson; AR—Steve Wilson, Steve Cole, Scott Henderson; CA—Jack C. Parnell, Terry Mansfield, Bill Griffin, Forest Tucker, John Turner; CO—James Ruch, Cher Threlkeld, Bob Hernbrode, Harlan Riffel; CT—Robert Jones, Paul Herig, Peter Good; DE—William Wagner, II; FL—Smokie Holcomb, Frank Montalbano, III, Frank Smith, Thomas Vaughn; GA—Leon Kirkland, Joe Kurz, Mike Jennings; HI—Libert Landgraf, Ron Walker; ID—Jerry Conley, Tom Reinecker, Tom Parker; IL—Michael Witte, Mike Conlin, James Moak; IN—James Ridenour, John Olson; IA—Allen Farris; KS—Bill Hanzlick, Kent Montei; KY—Peter Pfeiffer, William Graves, Lauren Schaaf; LA—J. Burton Angelle, Sr., Bennie Fontenot, Hugh Bateman; ME—Frederick Hurley; MD—Donald MacLauchlan, Jim Burtis, Mike Burch, Eral Hodil, Joe Schugars; MA—Richard Cronin, Dick Burrell, Bob Madore; MI—Gordon Guyer, Dan Tucker, Don Reynolds; MN—Larry Shannon, Roger Holmes, Dick Hassinger, Tim Burmicker; MS—William Quisenberry, III, Seth Mott, Jack Herring; MO—Larry Gale, Ray Evans, Ken Babcock, George Dellinger, Ollie Torgerson; MT—James Flynn, Arnold Olson; NE—Eugene Mahoney, Ken Johnson; NV—William Molini, George Tsukamoto; NH—Allen Crabtree, III, Howard Nowell, Charles Thoits; NJ—Russell Cookingham, Tony Petrongolo; NM—Harold Olson, Byron Donaldson, Gerald Gates; NY—Kenneth Wich, George Mattfeld; NC—Charles Fullwood, Hal Atkinson; ND—Dale Henegar, C. R. Grondahl; OH—Joseph Sommer, Pat Ruble, Gary Isbell; OK—Steven Alan Lewis, Byron Moser, Kim Erickson; OR—John Donaldson, Frank Newton; PA—Ralph Abele, Peter Duncan, III, Dick Snyder, William Shope; RI—Robert Bendick, Jr., Jim Meyers, Jim Chadwick, Mike Lapisky; SC—James Timmerman, Jr., Jeff Fuller, Joe Logan, Brock Conrad, Darrell Shipes, John Frampton, Billy McTeer; SD—James Salyer, David Hamm, Chuck Backland; TN—Gary Myers, Ron Fox, Hudson Nichols, Greg Wathen; TX—Charles Travis, Ted Clark, Bob Kemp; UT—William Geer, Ed Rawley, Bob Hasen; VT—Stephen Wright, Ben Day, Angelo Incerpi; VA—Richard Cross, Jr., Jack Raybourne, Jack Hoffman; WA—William Wilkerson, Jack Wayland, Rich Lincoln, Rich Poelker, Ken Dixon; WV—Ronald Potesta, Robert Miles; WI—James Addis, Steven Miller, Edward Frank; WY—William Morris, Doug Crowe.

The following individuals provided technical review of an earlier draft: William Gusey, Shell Oil Company; Michael Sale, Oak Ridge National Lab; Larry Harris, University of Florida; Kurt Fausch, Colorado State University; Donald Orth, Virginia Polytechnic Institute and State University; Tony Peterle, Ohio State University; James Teer, Welder Wildlife Foundation; James Peek, University of Idaho; Milton Weller, Texas A&M University; Frederic Wagner, Utah State University.

Special recognition is extended to Michael Knowles for his compilation, organization, and summarization of data that formed the basis of this document; Patricia Flebbe for her assistance in summarizing the fisheries information; and Glen Brink for his computer programing and data base management skills. Appreciation is also extended to David Chalk, Soil Conservation Service, for his assistance in coordinating the acquisition of state wildlife and fish agency data and Soil Conservation Service data on land use and land cover.

HIGHLIGHTS

Wildlife and fish are an integral component of all environments from pristine wilderness to the most intensively managed urban settings. The values associated with wildlife and fish have broadened from the utilitarian views held by early subsistence and market hunters to the recognition that animals contribute to the overall public welfare in a multitude of ways. This is reflected, in part, by increased nonconsumptive uses of wildlife and fish, increased membership in wildlife and fish organizations, increased public interest in policies and programs affecting wildlife and fish, and in the passage of laws intended to ensure protection and stewardship of the resource.

A national assessment of wildlife and fish is one of the reporting responsibilities of the USDA, Forest Service related to the Forest and Rangeland Renewable Resources Planning Act (RPA). The assessment is to serve as the technical basis for developing a national Forest Service Program guiding the management of natural resources. This assessment reports on the current status and recent historical trends of wildlife and fish resources, resource inventory and use projections, and implications and opportunities for resource management programs.

CURRENT STATUS AND RECENT HISTORICAL TRENDS

Four aspects of wildlife and fish resources that are important in a characterization of resource status include habitat, population, harvest, and number of users.

Recent Trends in Wildlife and Fish Habitat

To survive, fish and wildlife need habitat—the availability and appropriate mix of food, cover, and water. Land use and land cover patterns provided a coarse description of the amounts and quality of wildlife and fish habitats.

- *Forestland* has declined by 5% as a result of recent cropland and urbanland conversion. Significant declines in Southern pines, bottomland hardwoods, aspen-birch, and elm-ash-cottonwood have been observed. Mature and old-growth softwood stands are becoming increasingly rare in the major timber producing regions of the Pacific Northwest and South. Demand for eastern hardwoods has not kept pace with forest growth, resulting in greater acreage of older hardwood stands in the North.
- Over recent decades, *rangeland* has declined slightly. The majority of non-federal rangelands are in fair to poor condition. However, available evidence indicates range condition is improving with better management. Two important issues are the loss and fragmentation of grassland habitats in the East and degradation of riparian habitats in the arid West.
- Every state contains some *wetland* habitat. However, wetlands only account for 5% of the total land area in the contiguous U.S. Wetland area has declined significantly over the past several decades. Between 1954 and 1974 forested wetlands declined by nearly 11%; emergent wetlands declined by 14%; and estuarine wetlands declined by 6.5%.
- About 80% of the nation's *flowing waters* have problems with quantity, quality, fish habitat, or fish community composition. Water quality is affected by turbidity, high temperatures, nutrient surplus, toxic substances, and dissolved oxygen availability. Many of these quality-related problems are the result of soil and vegetative manipulation associated with agriculture, forestry, and other human activities.
- Increases in *cropland* area over the last 10 years have been accompanied by more intensive farming practices, larger farm size, and a reduction in shelterbelts, field borders, and odd habitat areas that were previously inconvenient to farm. Fencerow-to-fencerow farming has eliminated much nesting, feeding, and winter cover for wildlife and resulted in increased erosion which has degraded aquatic habitats.

Recent Trends in Wildlife and Fish Populations, Harvests, and Use

The current status and recent historical trend in populations, harvests, and uses of wildlife and fish resources are closely linked to habitat trends. Although trends vary by species category, those species associated with agricultural, mature and old-growth forest, native grassland, and wetland kinds of environments have had declining or unstable populations in the last 20 years.

- Although *nongame* bird surveys indicate that the majority of breeding bird populations have remained stable since the mid-1960s, a significant proportion (13%) of the breeding bird fauna has declined over a 20-year period. The number of breeding bird species that have shown recent population declines are more numerous in the East than the West. Breeding birds that have realized population increases tend to be those adapted to more intensive land uses particularly urban/suburban environments.
- *Migratory game bird* populations, except geese, have generally declined. Breeding duck populations have declined from 44 million in the early 1970s to about 30 million birds in the mid-1980s.
- *Big game* species across all regions have increased, except Pacific Coast deer. Populations of the two most commonly hunted big game species, white-tailed deer and wild turkey, have more than doubled.
- *Small game* population trends were divergent for agriculture and forest species. Those small game species associated with agricultural lands have shown significant declines over the last 20 years,

while most woodland populations have remained stable or increased.

- Trends in *furbearer* populations vary. Some commonly harvested species appear to have stable or increasing populations while other species, such as red fox and mink, have shown regional declines.
- While national and regional appraisals of how *fish* populations are changing are limited, specific regional studies indicate that the capacity of the nation's waters to support warm and coldwater fisheries has declined. The loss owes to human-caused degradation of aquatic habitats and introductions of competing fish species.
- There are 330 animal species that are listed as being *threatened or endangered*—a gain of 130 species since the last national assessment of wildlife and fish. In addition, there are approximately 1,000 candidate plant and animal species for which the Fish and Wildlife Service has sufficient information to initiate formal listing procedures.

Recent trends in the recreational use of wildlife and fish are a function of wildlife and fish availability and the public's relative preference for different kinds of recreational activities.

- Nonconsumptive recreation has increased at a substantially greater rate than other forms of wildlife and fish recreation. Most nonconsumptive wildlife and fish recreation occurs at or near people's homes or in association with other outdoor activities.
- The number of big game hunters has generally increased during the last 20 years, although more slowly now than before. The number of small game and migratory game bird hunters has shown recent declines and is likely a response to lower game populations, reduced access, and crowded hunting conditions. The number of trappers has recently declined in apparent response to declining fur prices, but may also be affected by public and legislative pressure to restrict this activity.
- The numbers of both recreational and commercial fishers have consistently increased during the last 20 years.

PROJECTED INVENTORIES AND USES OF WILDLIFE AND FISH

Resource inventory and use projections are an integral part of national resource assessments. The projections are suggestive of what the future resource situation may become based on recent experiences. A comparison of future inventories against anticipated uses provides insight into possible imbalances between the supply of and demands for wildlife and fish resources.

- In the coming decades, rangeland area will increase 5%; the acreage of forestland will decline by about 4%; needed cropland will probably decline; and wetland habitats will continue to be lost, but at a slower rate.
- State wildlife and fish agencies are optimistic about future big game populations and harvests with the expectation of stable or upward trends for all species.
- Small game population and harvest projections associated with agricultural habitats indicate a continued decline. Northern bobwhite populations and harvests are expected to decline; pheasant and rabbit populations and harvest are projected to increase only in the short-term as a result of the Conservation Reserve Program.
- The future number of participants in wildlife and fish recreation indicate that participation in coldwater fishing and nonconsumptive activities are expected to more than double by 2040. The number of hunters, in general, is expected to decrease as participation in big game and small game hunting declines.
- More hunters are expected to participate under fee-hunting situations in the future. As many as one in five hunters may be participating in some form of fee-hunting by 2040.
- A future of diminished habitat and lower populations of some species indicate that resource supplies may not support future levels of recreational demand. The potential gap of unmet demand is greatest for coldwater fishing, followed by migratory bird hunting, warmwater fishing, big game hunting, and small game hunting. The demand for nonconsumptive recreation does not appear to have any obvious future resource supply constraints.
- The substantial increases in demands for nonconsumptive uses and all forms of fishing imply increased density of use which may degrade the quality of the recreational experience for many people.

THE IMPLICATIONS AND OPPORTUNITIES FOR WILDLIFE AND FISH MANAGEMENT

The wildlife and fish inventory and use projections imply certain economic, social, and environmental consequences that could occur if resource use and inventories are not balanced.

- As wildlife and fish habitat is lost or made unavailable to the recreating public, and as expanding human populations result in more crowded conditions, future recreationists may have to travel greater distances to find suitable sites or may have to pay access fees. Recreation fees for fishing and hunting on private lands have increased rapidly in the past decade which may favor participation by the more affluent of society.
- Potential restrictions on commercial harvests and projected declines in hunting could severely impact local economies that are dependent upon commercial or recreational use of wildlife and fish resources. Because state wildlife and fish agencies derive operating funds primarily from licence fees and excise taxes on equipment, they could also be negatively impacted.
- Important social implications are associated with fish and wildlife resources including cultural,

psychological, physiological, and societal aspects of public welfare. Declining inventories and use restrictions infringe on the lifestyles of certain cultural groups and reduces or eliminates a recreational outlet for which few substitutes exist.

- The growing pressures on wildlife and fish resources are likely to be especially significant for endangered and threatened species, including those species not yet formally listed. As species become rare, or ultimately extinct, there is a reduction in biological diversity, a diminishing of the nation's natural heritage, and a forgoing of future options to meet society's various needs.

Growing human populations will continue to encroach on wildlife and fish habitat; and the demand for timber, livestock, water, and agricultural crops will conflict, in instances, with wildlife and fish resources. Future natural resource management must balance these multiple resource demands within the constraints defined by the environment. Management opportunities can be categorized into four areas: habitat, population, user, and planning.

Opportunities for management of habitat include:

- Protection of key habitats (including wetlands, native grasslands, old-growth forests, fish spawning areas, and critical habitat for threatened and endangered species) through public purchase, easement, leasing agreement, or establishment of natural areas.
- Increasing the size and distribution of key habitat tracts to preserve the natural diversity characteristic of a given region.
- Restoration of degraded ecosystems through direct manipulation of vegetation and water or controlling disturbance factors.

Opportunities for direct management of wildlife and fish populations include:

- Manipulation of populations through appropriate harvest strategies to ensure that populations remain within the productive capacities of their habitat.
- Reintroduction of species into areas where they have been displaced from suitable habitat or where suitable habitat has been developed.
- Increasing fish hatchery production through improved propagation practices, increasing the capacity of extant facilities, and the building of new facilities.

Opportunities for user management include:

- Increasing access to private lands by developing programs that would assist landowners in establishing wildlife and fish-related businesses.
- Increasing land acquisition and management of recreational use to increase the amount of habitat available to recreationists and to better distribute users across suitable sites.
- Increasing public education programs on the value and objectives of wildlife and fish management.
- Implementing techniques to monitor public attitudes and values associated with wildlife and fish resources to better address the public's changing needs and wants.

Opportunities for planning include:

- Increasing cooperation and coordination among the many agencies that have responsibility for management of habitat, wildlife and fish populations, and hunting and fishing.
- Integrating wildlife and fish management objectives more fully into the management of forest and rangelands for multiple resources.
- Through research, improving the information base (e.g., habitat inventories, population inventories, habitat-population relationships, valuation of wildlife and fish resources) needed to effectively manage the wildlife and fish resource.

Managing fish and wildlife resources will be especially challenging in the future because of competing demands for the nation's forest and range resource base. As one of the largest land-managing agencies in the federal government, the Forest Service has the opportunity to play an important role in directing the future wildlife and fish resource situation. This opportunity not only exists on vast acreages of national forests, but also in cooperative assistance programs, and by conducting and promoting research within and outside the agency. The nature and extent to which the wildlife and fish resource situation can be improved will be defined by the next Forest Service program. What this assessment has done is to provide planners with a factual and technical basis upon which to consider a number of Forest Service program alternatives.

Contents

An Analysis of the Wildlife and Fish Situation in the United States: 1989–2040

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INTRODUCTION

Wildlife and fish are important and integral components of environments ranging from pristine wilderness to the most intensively managed urban settings. They are critical to the functioning and persistence of ecosystems with numerous roles including pollination, seed dispersal and germination, nutrient cycling, herbivory, and predation, all of which are important in maintaining the ecological balance of plant and animal communities. The perceived values attributed to wildlife and fish have broadened from the utilitarian views held by early subsistence and market hunters, to the recognition that animals contribute to the overall public welfare in a multitude of ways. The values attributed to, and uses of, wildlife and fish resources are varied owing to the diverse interaction between the number and kinds of animals, and the desires of man.

Wildlife and fish resources possess regulatory and mobility characteristics that collectively make their management unique among other natural resources. Regulatory authority for wildlife and fish resources has its roots in Roman law and English common law. Wildlife and fish are regarded as common resources, owned by all citizens, yet held in trust by the states. The doctrine of state ownership designated that each state retain the primary regulatory and management authority of wildlife and fish. However, passage of the Lacey Act in the early 1900's marked the beginning of an expanding federal role in the regulation and management of wildlife and fish resources. Federal agencies now have stewardship responsibility for migratory birds, marine animals, and for animals on federally owned lands. Public ownership, management authority vested in state and federal agencies, and a mobile resource that does not recognize arbitrary land ownership boundaries, all interact to make the management of wildlife and fish complex and dependent upon cooperation among resource managing agencies and the public.

This report is about wildlife and fish resources—their habitats, populations, and uses. It is a report on how these attributes of wildlife and fish resources have changed in the last 20 years, what may happen in the future if current actions continue, what opportunities we have as a nation to direct that future, and finally how changing these actions could alter the future. The motivation for an evaluation of the nation's wildlife and fish resources stems proximately from recent federal legislation but ultimately from the public's desire and expectation that the stewards of these public resources be explicit and complete in their consideration of wildlife and fish in planning for and managing all natural resources. The public attitude concerning the management of natural resources has been reflected in a number of recent federal laws. This report is a response to one such law—the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA).

RENEWABLE RESOURCE PLANNING ASSESSMENTS

The national assessment of wildlife and fish is one part of the reporting responsibility of the USDA Forest Service related to the RPA. Resource assessments are technical reports about the nation's natural resources and are used as a basis upon which a second requirement of the RPA is satisfied—the development of a national program for the Forest Service. The Act was amended in 1976 by the National Forest Management Act which further directed the Forest Service to complete land management plans for each national forest as a more detailed part of the agency's planning responsibilities. The national forests are currently developing the first series of plans, while resource assessments and programs for minerals, range, water, recreation and wilderness, and wildlife and fish resources have been carried out in 1975, 1979, and 1984. Timber assessments have been completed since the late 1800's.

The Forest Service is not alone in its national planning requirements. Similar national planning mandates were established for the Soil Conservation Service on all non-federal lands with the passage of the Soil and Water Resources Conservation Act of 1977 (RCA). The Federal Land Policy and Management Act of 1976 (FLPMA) established a related requirement for inventories and documentation to support land use planning and policy development on lands administered by the Bureau of Land Management.

The legislative requirements for national resource planning generally follow a similar format. The resources are to be described in terms of their current and recent historical status and condition. In the case of wildlife and fish, this requirement translates into a characterization of the habitats, populations, users, and use of the resource. In addition, a projection must be made of resource attributes and an exploration of alternative future opportunities that could change the future resource situation. Finally, how the findings affect Forest Service resource management programs must be analyzed. The wildlife and fish assessment has been organized to be consistent with this national planning format.

ORGANIZATION OF THE 1989 WILDLIFE AND FISH ASSESSMENT

The 1989 national assessment of wildlife and fish has been structured as a planning document. The first chapter presents the current status and recent historical trends in wildlife and fish habitats, populations, nonconsumptive and consumptive users, and harvests. Each section of chapter 1 presents available information at the national, regional, and federal ownership levels. Information reported at the state level has been specifically excluded from this report since it is under the jurisdiction of the individual states.

The next three chapters present projections of the future resource situation. A major effort was made during the last 10 years to develop methods for evaluating future recreational uses of wildlife and fish (chapter 2) and future wildlife and fish inventories (chapter 3). A comparison of these projected levels of use and inventories (chapter 4) establishes a basis for identifying potential imbalances in resource supplies and demands.

The fifth chapter describes the social, economic, and environmental implications of the recent trends and future projections of wildlife and fish inventories and their uses. These implications provide the societal justification for future management actions that could improve the resource situation and ultimately enhance public welfare.

Major management issues, and the opportunities that exist to address them, are described in chapter 6. These issues and opportunities are discussed as changes that could be accomplished to improve the future wildlife and fish resource situation. However, opportunities to improve the resource situation can be expected to encounter obstacles in implementation. These obstacles include legal, political, institutional, economic, and biophysical limitations that, unless they are satisfactorily resolved through program implementation or additional research, will limit the full realization of resource improvement expected from the proposed opportunities.

The last chapter broadly identifies the implications of this assessment to the next Forest Service program. These implications are discussed with reference to their potential influence on national forest management, management programs on state and private forests and rangelands, and research programs carried out by the Forest Service.

To clarify terminology, a glossary is provided in appendix A, and Latin names of animal species mentioned in this report have been compiled in appendix B.

The content of this report, as well as previous RPA national assessments of wildlife and fish, is a product of the available information on habitats, populations, and use characteristics. There are many opportunities to improve the quality of data and analyses that could be used to evaluate the status of the nation's wildlife and fish resources. Nonetheless, this report represents the state-of-the-art and is the most comprehensive national effort ever undertaken to assemble historical data and synthesize related analyses to address the requirements implied by national planning legislation. Early in the planning for the 1989 wildlife and fish assessment, it was recognized that an improved technical report would be possible through cooperative efforts with various federal and state agencies. Within the U.S. Department of Agriculture, the Soil Conservation Service made a commitment to assist the Forest Service in collecting and synthesizing information for this report. Similarly, the Bureau of Land Management, the Fish and Wildlife Service, and the National Marine Fisheries Service contributed to the assessment format and provided data and analyses for portions of this report. State wildlife and fish agencies also reviewed the proposed approach for data acquisition and analysis, provided data, and reviewed the document for technical adequacy. Although the Forest Service has the mandated responsibility to assess the nation's wildlife and fish resources, the collaboration that went into the completion of this report makes this assessment a multi-agency effort—the product of which is summarized in the pages that follow.

CHAPTER 1: CURRENT STATUS AND RECENT HISTORICAL TRENDS OF WILDLIFE AND FISH RESOURCES

One objective of renewable natural resource assessments is to evaluate the potential environmental, social, and economic implications of resource production and consumption trends (Hamilton and Thorton 1982). An evaluation that attempts to identify and address future resource management issues first must address an appropriate historical perspective to provide a context within which to interpret present trends. The last national assessment of wildlife and fish (USDA Forest Service 1981) provided recent historical trends through the mid-1970's. Recent history for this assessment is defined as 1965–1985. However, data through 1988 is presented when available. The trends are discussed with respect to the factors considered responsible for the dynamics observed over this approximate 20-year period.

For this assessment, four aspects of wildlife and fish resources are defined, each important to a characterization of resource status: habitats, population levels, number of users, and harvest levels. Owing to the diversity of habitats and the large number of resident and common migrant species, this chapter addresses the four resource aspects by major habitat or species categories. The habitat categories include forestland, rangeland, wetland, water, and agricultural habitats. The species categories include nongame, migratory game birds, big game, small game, furbearers, fish, and threatened and endangered species.

The data available to support an assessment of wildlife and fish come largely from existing information of the Forest Service and cooperating state and federal agencies. In general, the data were not collected specifically for a national assessment of wildlife and fish. No standard national or regional inventory that permits a consistent summarization of wildlife and fish resources exists (Hirsch et al. 1979, Hoekstra et al. 1983). Consequently, the extent to which habitat, population, user, and harvest trends can be discussed depends on the information available from various sources.

The review of the current status and historical trends in wildlife and fish resources is organized into two major sections: *National and Regional Statistics*, and *Wildlife and Fish Resources on Public Lands*. Within the first section, a national level summary discusses the broad emerging historical trends in wildlife and fishery resources observed in the United States. More refined geographic detail is reviewed within four multi-state assessment regions defined by the Forest Service for program planning purposes and include the North, South, Rocky Mountain, and Pacific Coast regions (fig. 1). Regions defined by other criteria are also used when they are established in wildlife and fishery usage. These include waterfowl flyways, Breeding Bird Survey regions, or Bureau of Census regions. The second section of this chapter examines the distributional characteristics of wildlife and fish resources on public lands emphasizing lands administered by the National Forest System and Bureau of Land Management.

NATIONAL AND REGIONAL STATISTICS

Available information regarding the current status and historical trends in wildlife and fish resources is biased heavily towards those few species that are of commercial importance or taken for sport. Information was also available on some threatened and endangered species and nongame birds because of public concern for preserving these species or for their high nonconsumptive recreational value. However, small mammals, amphibians, reptiles, fish, and invertebrates are largely unrepresented in state or federal inventories. Therefore, the trends reviewed here are admittedly incomplete regarding the full compendium of species that play critical roles in the natural environment. Nevertheless, the information reviewed herein does provide insights into the status of wildlife and fish resources in the United States.

Wildlife and Fish Habitat

Wildlife and fish habitat in its most basic sense can be defined as the availability and appropriate mix of food, cover, and water. Habitat represents a spatial

concept characterized by a particular combination of physical and biotic factors within a defined geographic area that interact to determine whether a particular species can survive and reproduce (Partridge 1978). Except for special cases (e.g., critical habitat for some threatened or endangered species), national inventories addressing the amount of habitat specific to a single species or species group do not exist.

Alternatively, habitat may be descriptively defined based on landscape attributes. In many cases, vegetation features can be used to define habitat types that can be inventoried over large geographic areas. Similarly, stream characteristics can form the basis of an inventory of fish habitat. Based on this definition of habitat, the inventory represents a description and estimate of land area that supports a faunal community as opposed to an estimate of the amount of suitable habitat for any given species. This alternative definition forms the basis for the following discussion of habitat trends.

Overview of Land Use and Land Cover Trends

Wildlife and fish are products of how the land is covered (i.e., vegetation present) and how the land is used (e.g., grazed, cropped, urbanized). As indicated in figure 2, major land use categories have changed very little. The most obvious pattern has been a reduction in land supporting natural vegetation types concomitant with increasing land modified by people. Acreage in both forest and range categories has declined by about 5% since about 1960. After declining slightly through the mid-1970's, land area devoted to crop production showed a 3% increase by the early 1980's.

Trends in urbanland have been difficult to estimate precisely because of inconsistencies in definitions (USDA Soil Conservation Service 1987). Frey's (1983) summary of urbanland trends indicates that it has increased from approximately 25 million acres in 1960 to 47 million acres in 1980—an increase of 88% over that 20-year period. Urban expansion has both direct (removal of habitat) and indirect (increased human-related disturbance) impacts on wildlife and fish habitats. Consequently, urbanland uses are discussed as a disturbance factor rather than a specific category of wildlife or fish habitat.

The three land uses in figure 2 constitute a broad classification within which to discuss terrestrial wildlife habitats. Characteristics of the nation's aquatic environments address fish habitat, and wetlands are discussed as important habitats transitional between terrestrial and aquatic ecosystems.

Forestland Habitats

Forestland is defined as land at least 10% stocked by forest trees of any size, or formerly having such cover, and not currently developed for other uses (USDA Forest Service 1981). Forested ecosystems are extensive and diverse. Ninety percent of the resident or common migrant vertebrate species in the United States use forested ecosystems to meet at least part of their life requisites. At least 90% of the total bird, amphibian, and fish species and at least 80% of mammal and reptile species utilize forest ecosystems (USDA Forest Service 1979).

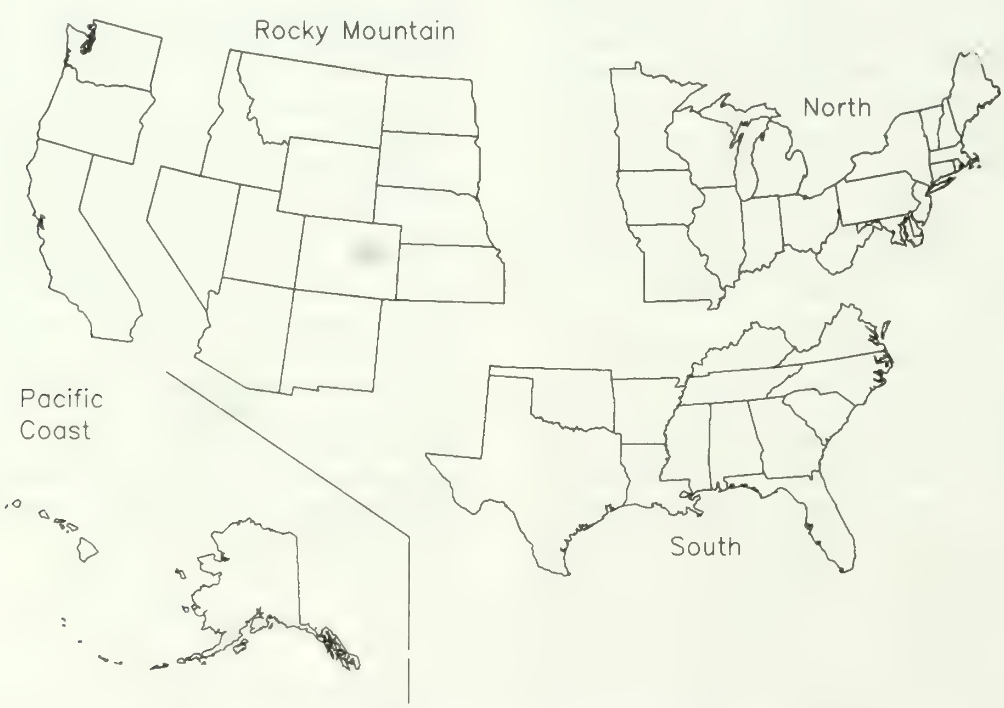


Figure 1.—Forest Service assessment regions.

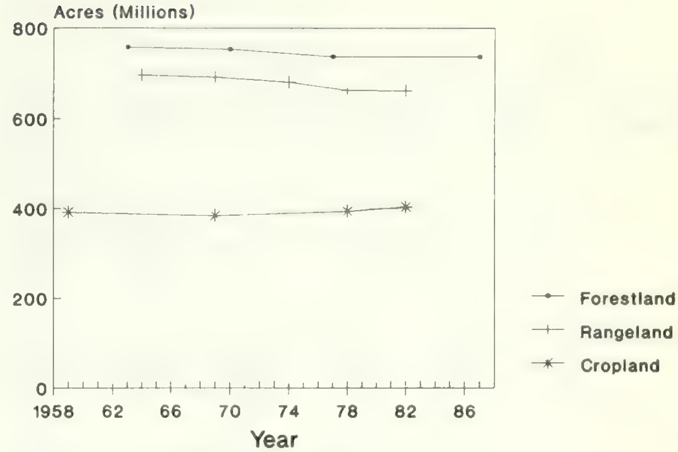
Forestlands currently comprise nearly a third of the total terrestrial land base; however, the extent of forestland has been diminishing (fig. 2). The losses have been attributed to conversion to cropland and pastureland, urban development, and highway and reservoir construction. The distribution of forestland is split evenly between the eastern and western assessment regions. The Pacific Coast region contains the most forestland acres; the Rocky Mountain region has the least.

The majority of the forestland acres recently lost occurred in the eastern half of the country, particularly in the South where forest has declined by 20 million acres over the last decade (table 1). This was expected because of the higher population and economic activity in the East (USDA Forest Service 1982). Forestland acres in the Rocky Mountains and Pacific Coast have remained relatively stable since the early 1960's.

Although complex relationships exist between wildlife and forested environments, it is possible to generalize the description of forest environments to obtain reasonable interpretations for trends in wildlife habitats. Cover type, successional stage, and spatial arrangement affect the kinds, numbers, and distribution of animals which inhabit forest environments. Unfortunately, forest inventories have not been uniformly designed to evaluate these particular attributes. Recent historical trends must be synthesized by gleaning data from existing inventory information compiled for other forest uses. Specifically, information exists on trends in forest ecosystem types and successional stages (as measured by stand-size class) for commercial timberland only. Commercial timberland is land capable of producing 20 cubic feet of wood per acre per year, and which is available for successive harvests of timber products (USDA Forest Service 1982). Similar data on noncommercial forestlands, including those in parks and wilderness, are not available.

Changes in forest types strongly influence wildlife and fish community composition. The forest types discussed in this document are those defined by the Forest-Range Environmental Study (FRES) (Garrison et al. 1977). Because of variation in inventory techniques and standards, historical trends must be interpreted cautiously, particularly in the western regions (USDA Forest Service 1982).

Eastern commercial forests are currently represented by 10 separate types including four softwood and six hardwood forest types (table 2). The most common eastern forest type is oak-hickory, which represents about 24% of the national commercial timberland area. Area trends in oak-hickory have fluctuated. From 1963 to 1977 the amount of land classified as oak-hickory declined by approximately 7 million acres. The decline was largely restricted to the North where forest clearing for crop and dairy farms, and management actions that converted oak-hickory stands to other forest types explain the change. The lack of a market for low-quality hardwoods has discouraged managing for oak-hickory



Source: Frey and Hexem (1985); USDA Forest Service (1965, 1974, 1982); Bones [in press]

Figure 2.—Recent trends in major land use categories in the United States.

Table 1.—Regional trends in forestland in the United States (1963–1985).

Region	1963		1970		1977		1987	
	Million acres (% of total)							
North[1]	178	(24)	186	(25)	178	(24)	182	(25)
South[2]	220	(29)	212	(28)	207	(28)	188	(26)
Rocky Mountain[3]	143	(19)	138	(18)	138	(19)	138	(19)
Pacific Coast	216	(29)	217	(29)	214	(29)	220	(30)

[1]*Includes ND, SD (east), NE, KS, KY.*
[2]*Does not include KY.*
[3]*Does not include ND, SD (east), NE, KS.*
Source: Bones (in press), USDA Forest Service (1965, 1974, 1982).

forests (USDA Forest Service 1982). Since 1977, the area of the oak-hickory type has increased, primarily in the South. Although specific reasons were not cited, Bones (in press) implied that natural succession and the harvesting of pine from oak-pine stands has led to a significant expansion of oak-hickory forests over the last decade.

Eastern hardwood types that have shown significant proportional losses (at least 10% of the 1963 acreage) include oak-gum-cypress, aspen-birch, and elm-ash-cottonwood. In recent years, changing land-use patterns have adversely affected the oak-gum-cypress type. Forests on the alluvial soils of the Mississippi Valley have been extensively cleared for agriculture (Bones in press). Much of the remaining bottomland forests are found as stringers along streams where the soil is too wet for profitable cropping or grazing (Rudis and Birdsey 1986, USDA Forest Service 1982).

Table 2.—Recent trends in eastern commercial forestland by forest types.

Region	Year	White-jack-red pine	Longleaf-slash pine	Loblolly-shortleaf pine	Spruce-fir	Oak-pine	Oak-hickory	Oak-gum cypress	Elm-ash-cottonwood	Maple-beech-birch	Aspen-birch
					Thousand acres						
North[1]	1963	10,680	—	3,818	19,623	2,266	58,896	1,678	18,301	32,812	23,715
	1970	11,910	—	3,422	18,899	4,085	55,536	1,361	21,971	30,657	20,484
	1977	11,455	—	3,423	17,552	4,170	49,956	623	19,074	35,821	19,243
	[3]1987	13,349	—	2,340	16,825	3,550	47,124	795	11,283	43,384	17,774
South[2]	1963	440	25,977	54,177	15	24,675	57,067	36,110	2,102	506	—
	1970	257	18,314	49,409	13	30,942	56,324	29,268	2,756	482	—
	1977	370	16,754	46,576	8	30,470	58,939	26,062	3,243	425	—
	[4]1987	514	15,491	46,248	18	27,775	70,559	27,332	3,007	876	—
Total East	1963	11,120	25,977	57,995	19,638	26,941	115,963	37,788	20,403	33,318	23,715
	1970	12,167	18,314	52,831	18,912	35,027	111,860	30,629	24,727	31,139	20,484
	1977	11,826	16,755	49,999	17,560	34,639	108,895	26,685	22,318	36,246	19,243
	1987	13,863	15,481	48,588	16,843	31,325	117,683	28,127	14,290	44,219	17,777

[1]*Includes ND, SD (east), NE, KS, and KY.*
[2]*Does not include KY.*
[3]*Does not include KY, includes SD (east and west).*
[4]*Includes KY.*
Source: Haynes (in press), USDA Forest Service (1965, 1974, 1982).

Aspen-birch, found in the North region, has been declining as a consequence of uninterrupted succession. Aspen-birch is a pioneer type on recently disturbed sites; when logging, fire, or other natural causes do not set succession back, this type is replaced by more shade-tolerant species such as maple, beech, and hemlock.

Following moderate acreage increases during the 1963–1977 period, elm-ash-cottonwood has declined by 8 million acres. The rapid spread of Dutch elm disease partially explains this trend. In many cases, elm is being replaced by more aggressive and fast-growing species such as red maple which is becoming more prominent particularly in the Northeast (Bones in press).

Some of the greatest proportional losses, for either hardwood or softwood types, have occurred in southern longleaf-slash and loblolly-shortleaf forests. Two significant reasons for the decline in these types have been cited (Bones in press, USDA Forest Service 1982). The first was that a lack of regeneration following harvest permitted encroachment by hardwoods resulting in conversion to oak-pine or oak-hickory. Secondly, less farmland has been abandoned. Until the early 1950's, the reversion of idle farmland accounted for the apparent stability in softwood acreage. The decline in the two southern pine types is particularly worrisome because the endangered red-cockaded woodpecker is an obligate inhabitant of these softwood types. Lennartz et al. (1983) estimated that the mature pine habitats required by this species had declined by 13% in 25 years.

Commercial forests in the western United States are dominated by softwoods (table 3). Because of changes in inventory standards and definitions, meaningful historical interpretations cannot be made (USDA Forest Service 1982). An additional caveat is that reported losses do not necessarily reflect conversion of forest to non-forestlands. Designation of forestland as wilderness removes that land from the commercial timberland base, but this should not be interpreted as a loss of forestland habitat.

Douglas fir and ponderosa pine are the most common western forest types, comprising nearly 45% of the West's commercial timberland. Fir-spruce, hemlock-Sitka spruce, and lodgepole pine constitute an additional 39% of the western commercial forestland base. The remaining softwood types, including larch, redwood, and western white pine among others, account for less than 4% of the commercial forestland base. In addition to these softwood types, western hardwoods comprised about 12% of the 1987 commercial timberland base. Although of limited value to the timber industry, western hardwoods are important for wildlife habitat and watershed protection.

Forest succession is a process whereby vegetation composition and structure change over time as the plant community evolves from bare ground to the climax state. Identifiable stages in this sequence are often called seral or developmental stages (Odum 1971). Verner and Boss (1980) suggested four seral stages for forest communities including grass/forb, shrub/seedling/sapling, pole/medium tree, and large tree. As forest communities progress through this sequence, the fauna changes, too. Maintaining the diversity of wildlife species that are potential inhabitants of any forest community requires that all seral stages be represented. For this assessment, stand-size classes for commercial timber were available

Table 3.—Recent trends in western commercial forestland by forest types.

Region	Year	Douglas fir	Ponderosa pine	Western white pine	Fir-spruce	Hemlock-Sitka spruce	Larch	Lodgepole pine	Redwood	Other softwood	Western hardwood
						Thousand acres					
Rocky[1] Mountain	1963	13,447	18,881	2,360	8,962	200	2,669	13,163	—	—	5,941
	1970	11,885	14,454	631	9,800	896	2,032	9,940	—	—	4,272
	1977	12,220	14,673	320	10,124	1,246	1,749	9,816	—	507	4,555
	[2]1987	13,304	13,714	260	11,009	1,489	1,749	9,397	—	301	4,810
Pacific Coast	1963	23,905	17,116	2,643	6,654	9,808	863	2,633	1,596	—	5,146
	1970	18,902	13,509	198	8,029	9,922	711	3,294	803	—	8,545
	1977	18,677	11,976	126	9,732	11,620	683	2,919	662	—	10,308
	1987	19,023	10,927	14	15,843	9,495	852	2,178	1,102	492	11,028
Total West	1963	37,352	35,997	5,003	15,616	10,008	3,532	15,796	1,596	—	11,087
	1970	30,787	27,963	829	17,829	10,818	2,743	13,234	803	—	12,817
	1977	30,897	26,649	446	19,856	12,866	2,432	12,735	662	507	14,862
	1987	32,327	24,641	274	26,852	10,984	2,601	11,575	1,102	793	15,838

[1]*Does not include ND, SD (east), NE, and KS.*
[2]*Does not include SD.*
Source: Haynes (in press), USDA Forest Service (1965, 1974, 1982).

as indicators of forest seral stages. Stand-size is defined by the predominant size of trees stocking a stand and include seedling/sapling, poletimber, sawtimber, and nonstocked stands.

In 1987, slightly more than half (242 million acres) of the nation's commercial timberland was classified as sawtimber. The number of acres classified as sawtimber increased between 1963 and 1987 (table 4)—a trend due primarily to ageing eastern forests. Since 1963, northern sawtimber stands have increased by nearly 22 million acres or 40%. Sawtimber stands have remained relatively stable in the West over the same period.

Of the remaining size classes stocked with timber, the greatest acreage occurs in the East. Over 80% of the poletimber occurs in the eastern regions. Increases in poletimber acreage have occurred primarily in the Pacific Coast, with declines being observed in the Rocky Mountains and South. About 20% of the commercial forestland acreage exists in seedling/sapling stands—a proportion that has been steadily declining since 1970. The majority of seedling/sapling stands exists in the East; the North and South are the only regions to lose substantial acres of this size class—nearly 25% of the acres that existed in 1977.

An important issue related to stand-size class is the concern for old-growth forests and the obligate inhabitants of this successional stage including such species as the red-cockaded woodpecker in the South, the spotted owl in the Pacific Northwest, and the Sitka black-tailed deer in Alaska. Harris (1984) estimated that of the 118 vertebrates which inhabit western Oregon's coniferous old-growth, 40 species cannot survive in any other seral stage.

Stand-size class is not the best indicator of the amount of forestland in mature successional stages. Age, although a better indicator of mature or old-growth forests, is also insufficient. Important structural characteristics such as snags, dead and down woody material in various stages of decay, multi-layered canopy, and patchy understory (Franklin et al. 1981, Harris 1984) may be absent in intensively managed mature forests.

The definition of "old-growth" is complex and varies by region and by forest type. The result has been a lack of consensus on a general definition (Mannan 1980, Spies and Franklin 1988). Consequently, it is difficult to precisely quantify trends in old-growth forest area. All indications, however, are that old-growth is becoming rare (Harris 1984) and is likely to be less extensive and more fragmented in the future (Fosburgh 1985b). Thomas et al. (1988) reported only 2% to 15% of the presettlement virgin timber (excluding the Alaskan taiga) remains nationwide. Similarly, Spies and Franklin (1988) have estimated that only about 17% of the original old-growth that existed in the early 1800's remains in the Douglas-fir region of western Oregon and Washington. In the last century, old-growth forests have been almost completely cut-over on private lands (Fosburgh 1985b). In the East, sawtimber stands are predominantly young-growth and are comprised of trees in the lower end of the sawtimber size class. Conversely, the remaining sawtimber in the West is primarily found in old-growth stands (USDA Forest Service 1982).

A final characteristic of forested habitats, and one that is inadequately addressed in current forest inventories, is the size, shape, and distribution of forestlands, forest types, and successional stages. There is an increasing recognition that the pattern of forest environments across landscapes needs to be considered in wildlife habitat assessments (Noss 1987, Risser et al. 1984). Although some wildlife species are benefited by increases in the spatial

Table 4.—Trends in stand-size class by assessment region.

Class	Year	Total	North[1]	South[2]	Rocky[3] Mountain	Pacific Coast
			Thousand acres			
Sawtimber	1963	208,945	52,974	68,828	38,639	48,504
	1970	215,876	58,949	74,041	36,555	46,321
	1977	215,435	59,098	71,246	38,545	46,545
	1987	242,449	74,548	78,321	41,981	47,599
Poletimber	1963	164,794	64,808	71,580	19,063	9,343
	1970	126,794	60,156	46,151	12,129	8,256
	1977	135,610	55,543	58,316	11,708	10,042
	1987	136,773	60,445	54,888	9,454	11,986
Seedling sapling	1963	99,573	39,327	49,254	4,352	6,640
	1970	131,368	49,223	67,578	5,229	9,337
	1977	115,032	46,676	53,286	4,955	10,115
	1987	92,436	31,547	44,883	5,323	10,683
Nonstocked	1963	35,533	14,680	11,407	3,569	5,877
	1970	20,721	9,571	4,771	2,671	3,707
	1977	16,408	4,823	5,198	2,556	3,831
	1987	11,649	2,247	5,380	2,186	1,836
All	1963	508,845	171,789	201,069	65,623	70,364
	1970	499,692	177,901	192,542	61,631	67,622
	1977	482,485	166,141	188,045	57,765	70,543
	1987	483,309	168,788	183,473	58,944	72,104

[1]*Includes ND, SD (east), NE, KS, and KY.*
[2]*Does not include KY.*
[3]*Does not include ND, SD (east), NE and KS.*
Source: USDA Forest Service (1965, 1974, 1982), Waddell, pers. comm., 1989.

heterogeneity of forestlands, other species appear to require large tracts of homogeneous forest. Providing habitat for both kinds of species is necessary if the diversity of species inhabiting forest environments is to be maintained. There is a concern, both in the East (Burgess and Sharpe 1981) and in the West (Harris 1984), that increasing forest fragmentation will jeopardize the existence of some species as functioning members of certain faunas. At the present time, the most vulnerable forest environments are large tracts of mature and old-growth forests.

Evaluating the impacts of changing forest type, timber size-class, and their interspersion and juxtaposition on wildlife and fish is difficult since species respond differently depending on their habitat requirements. Quantitative analyses are being developed to permit resource planners to explicitly analyze species' responses to forestland changes. An example is the life form system developed for the Blue Mountains in Oregon and Washington (Thomas 1979). Other systems have been developed to specifically utilize Forest Service regional inventories of commercial forestland (McClure et al. 1979, Sheffield 1981).

In a case study for this assessment, we modified the models developed by McClure et al. (1979) and Sheffield (1981) to assess the status and trends in commercial forest habitats for gray squirrel, pileated woodpecker, pine warbler, prothonotary warbler, and red-eyed vireo in the five coastal states from Virginia to Florida. Species were chosen to reflect several forest types and successional stages.

The results of the analysis using the most recent forest survey data in those five states indicate that the rarest habitat of the five species modeled is that required by the prothonotary warbler, followed by the pileated woodpecker (table 5). The prothonotary warbler's habitat includes stands with intermediate to dense canopy cover, in both mesic and hydric sites, and in the intermediate to mature stage of succession. Pileated woodpeckers need dense mature stands on mesic sites.

The gray squirrel, red-eyed vireo, and pine warbler had relatively large amounts of suitable habitat in the Southeast. The gray squirrel habitats are pole and sawtimber stands with 40% to 75% canopy cover, 31% to 75% stocked with hard and soft mast trees, and a well developed understory. Red-eyed vireos prefer hardwood stands over 70 years old with more than 60% canopy closure. The habitats of the pine warbler are described as pole and sawtimber stands of pine forest types with a sparse understory.

South Carolina was the only state suitable for an assessment of trends because two forest inventories that

Table 5.—Analysis of status and trend of commercial forestland habitat for five selected species in the Southeast (SE) and South Carolina (SC).

Species	% good habitat	% fair habitat	% no habitat
Gray Squirrel			
SE	48.5	23.1	28.4
SC 1978	47.4	25.0	27.6
SC 1986	48.5	21.8	29.7
Pileated Woodpecker			
SE	7.3	18.5	74.2
SC 1978	7.1	17.7	75.2
SC 1986	6.7	16.3	76.9
Prothonotary Warbler			
SE	1.9	2.1	96.0
SC 1978	10.1	6.7	83.2
SC 1986	2.1	2.4	95.5
Pine Warbler			
SE	19.5	10.2	70.3
SC 1978	26.9	9.2	63.9
SC 1986	23.8	10.5	65.6
Red-eyed Vireo			
SE	18.3	31.1	50.6
SC 1978	9.5	30.1	60.4
SC 1986	14.3	29.6	56.1

included appropriate variables (1978 and 1986) had been conducted. The rare habitats declined there over the trend period (table 5). The greatest decline occurred in the habitat of the prothonotary warbler. Pileated woodpecker habitat declined slightly as did pine warbler habitat. These trends are consistent with the noted losses of sawtimber-sized stands, the reduction in bottomland hardwoods (e.g., the oak-gum-cypress forest type), and the declining acres in pine types. The development of similar models for other species and regions will require further research before future wildlife assessments can have nationally complete information on wildlife habitat of this nature.

Rangeland and Pasture Habitats

Rangelands include those acres where the potential natural vegetation is mostly grass, grasslike plants, forbs, and shrubs (Short 1986), plus cropland used for pasture. Rangelands often have been evaluated in terms of their capability to support livestock. However, people increasingly recognize that rangeland ecosystems are also important for their recreational and ecological value. Growing public interest in range management verifies interest in these multiple resource benefits (Joyce in press).

Rangeland habitats support a wide diversity of wildlife and fish species. Of the total mammalian and avian species found in the United States, 84% and 74%, respectively, are associated with rangeland ecosystems during some part of the year (USDA Forest Service 1979). Species associated with aquatic environments are the least represented vertebrate groups due to the arid or semiarid climate of most rangeland environments. Only 38% of the nation's fishes and 58% of the amphibians are represented in rangeland ecosystems.

Table 6.—Regional trends in nonforest pasture- and rangeland in the conterminous United States (1964–1982).

Land use	1964		1969		1974		1978		1982	
	Million acres (% of total)									
North[1]	55	(8)	50	(7)	45	(7)	40	(6)	38	(6)
South[1]	177	(25)	180	(26)	178	(26)	171	(26)	178	(27)
Rocky Mountain	404	(58)	403	(58)	398	(59)	394	(60)	388	(59)
Pacific Coast[2]	58	(8)	56	(8)	57	(8)	56	(8)	55	(8)

[1]West Virginia is included in the South instead of the North.
[2]Does not include Alaska or Hawaii.
Source: Frey and Hexem (1985).

Recent changes in rangeland and pasture acreages have been minor. Since the mid-1960's total acres in pasture and rangeland have declined by 5% (fig 2). Factors contributing to the noted losses include conversion to cropland, withdrawal of land for recreational, wildlife, and environmental purposes, and losses to urban expansion (Frey and Hexem 1985). The distribution of rangeland varies considerably by region. In 1982, the Rocky Mountain region accounted for nearly 60% of the total pasture and rangeland acres in the conterminous United States while the North contributes only about 6% to the total.

Regional rangeland area trends vary somewhat from the national figures. The North has had the greatest relative decline since the mid-1960's, declining by 31% (table 6). However, the North has the least amount of rangeland habitats which magnifies the proportional reduction noted. Rangeland area in the South has remained stable in recent time, fluctuating between 170 and 180 million acres. Declines in the West have been relatively minor—4% in the Rocky Mountains and 5% in the Pacific Coast.

Given the minor changes in pasture and rangeland area, changes in the condition or characteristics of rangeland environments are, in general, more important in evaluating wildlife and fish habitat suitability than conversion to other land uses. Evaluating rangeland in terms of wildlife habitat is complicated, as in all habitat types, by the multiplicity of wildlife responses. Rangeland characteristics that may be detrimental to some species are beneficial to others. This difficulty has been compounded because wildlife managers had not, until recently, developed a consistent system to assess wildlife habitats in rangelands (National Academy of Sciences, National Research Council 1982). The Forest Service and Bureau of Land Management have recently completed a procedure for evaluating wildlife and fish habitats in rangeland environments in the Great Basin of southeastern Oregon (see Maser and Thomas 1983). Development of similar procedures in other regions are

needed for application in national assessments. Despite the absence of a national rangeland evaluation system, a discussion of the important factors affecting wildlife and fish response to range condition provides a qualitative assessment of rangeland habitats. These factors include interspecific competition, vegetation composition changes, effects from human management and development, and spatial patterns of native range ecosystems.

Interspecific competition occurs when two or more species require the same resources that are in short supply. Much scientific literature concerns domestic livestock competition with large ungulate species. There appears to be little doubt that, historically (1920–1940), domestic animals outcompeted wild animals in the West; although grazing pressure has declined significantly since that time, competition still exists (Wagner 1978). Few people disagree that western rangelands are of much reduced quality for grazing herbivores compared to what was present when livestock were first introduced (National Academy of Sciences, National Research Council 1982).

A more recent issue concerning interspecific competition involves wild horses and burros. Originally brought to this country by Spanish conquistadors in the early 1500's, herd sizes have grown steadily through natural reproduction and as animals escaped or were released from captivity (Sowell et al. 1983). Between 1974 and 1980, wild horse numbers grew from 42,700 to 55,400 (Administration of the Wild Free-Roaming Horse and Burro Act 1980). As populations have increased, concern has been raised over vegetation and soil impacts as well as competition with native wildlife (USDA Forest Service 1981). Although specific cases of range degradation involve wild horses and burros, and though many investigators suspect that competition occurs, quantifying the extent and nature of the problem requires further examination (Wagner 1983).

In addition to reducing the availability of forage for wild animals, grazing also alters vegetation composition. The National Association of Conservation Districts (1979) found that brush species had replaced many of the grass and other desirable forage species on 200 million acres in the Southwest and that 77% of the nation's private rangelands needed some form of conservation treatment. Invasion by shrub species in arid grassland communities, caused by grazing and fire control, can significantly alter faunal composition. Examples of how such vegetation changes negatively impact wildlife species include bighorn sheep, pronghorn, sage grouse, masked bobwhite quail, and northern aplomado falcon (Buechner 1961, Gable and Dobrott 1988, Morgan 1971, Schneegas 1967, USDI Fish and Wildlife Service 1986b). However, shrub invasion may have positive impacts on other species, such as mule deer (Wagner 1978). By favoring moderate topography near water, cattle may damage riparian vegetation and stream habitat quality (Kauffman and Krueger 1984, Thomas et al. 1979, Wagner 1978). The need to consider riparian ecosystems in future land management planning is emphasized when one considers that 70% to 90% of riparian ecosystems have been lost to human activities (Ohmart and Anderson 1986).

Range management activities and human development also impact rangeland wildlife species. Certain techniques to improve range for livestock including herbicide applications to control shrubs, pinyon-juniper removal, planting of exotic plant species, predator control, and livestock industry pressure to limit ungulate populations all affect wildlife community composition and the abundance of certain species (Joyce in press, Wagner 1978). Similarly, as human populations have increased, demands for agricultural commodities and subdivision of rangeland environments have increased. This development has tended to occur in valleys and lower slopes which conflicts directly with critical winter range for many wild ungulate species. Land use intensification related to maximizing livestock production, crop production, or human development will adversely affect the diversity and abundance of animals associated with rangelands unless consideration is given to wildlife and fish habitat requirements in the planning for range management activities.

As with forest habitats, the spatial pattern and particularly the fragmentation of native rangeland vegetation cause concern because they affect wildlife communities. In his study of Missouri's tall grass prairies, Samson (1980) concluded that there was an urgent need to consider the size and distribution of habitats with particular attention given to species requiring large contiguous habitats. Another study conducted in Illinois (Graber and Graber 1983) indicated that loss of grassland habitat was responsible for the dramatic decline in prairie birds. The upland sandpiper, bobolink, dickcissel, grasshopper sparrow, savannah sparrow, and Henslow's sparrow all declined by over 90% from the late 1950's to the late 1970's.

Native prairie vegetation is the most vulnerable range ecosystem to fragmentation effects analogous to old-growth forests. A few large and many small tracts of native grassland vegetation remain or have been reestablished. Efforts to reestablish native prairies during the last 20 years have emphasized plant species (see Jordan et al. 1987). As prairie habitats are restored, managers must recognize the wild animal component when evaluating grassland environments.

Unfortunately, quantitative information on the recent trends in rangeland characteristics that are representative of broad regional areas currently do not exist. However, livestock numbers and range condition ratings provide surrogate measures that reflect, in part, the intensity of livestock management.

Trends in livestock numbers vary by assessment region and are reviewed in detail by Joyce (in press). In the North, the number of cattle has shown a general decline. Since 1975, the number of animals has decreased from 38 to approximately 30 million animals.

Trends have been similar in the South and Rocky Mountains, with the number of cattle declining by 12 and 8 million animals after reaching peaks of 50 and 38 million in the mid-1970's, respectively. The Pacific Coast region has shown slight (500,000 animals) increases in cattle numbers since the mid-1970's; however, the magnitude of the change is minor relative to the magnitude of the decline noted in other regions. The nationwide decline in livestock numbers is attributed to changing consumer preference away from red meat consumption (Council on Environmental Quality 1985), and land use shifts from cropland pasture to cropland use for crops (Joyce in press).

Range condition has been defined as the departure of a site's vegetation composition from that expected under the climax plant community (Stoddart et al. 1975). Sites with high similarity to the climax community are rated as "excellent," while sites with low similarity are rated as "poor." This rating was based on a plant's susceptibility to grazing; a causal relationship between livestock overgrazing and range in poor condition was assumed (Joyce in press).

As reported by the USDA Soil Conservation Service (1987), the majority (47%) of nonfederal rangelands was classified in fair condition; 4% was in excellent condition; 31% was rated in good condition; and 17% was in poor condition. The Soil Conservation Service also reported that range condition trends on nonfederal rangelands were static on 69% of the land, improving on 16%, and deteriorating on 15%. Although changes in inventory methodology have taken place, the Soil Conservation Service's data indicate that from 1963 to 1982 nonfederal rangeland condition has improved.

Although livestock numbers have declined nationwide and in most assessment regions, and though range condition on nonfederal rangelands appears to be improving, evaluating the impact of these trends on wildlife is difficult. Information concerning grazing capacity and how much available forage is allocated to livestock and other herbivores is required to assess more accurately the status and condition of rangeland ecosystems as wildlife habitat.

Wetland Habitats

Wetlands are transitional between terrestrial and aquatic systems. Either the water table is at or near the surface, or shallow water covers the land. Water saturation is predominantly responsible for the edaphic properties and the floral and faunal composition characteristic of wetland systems. Specifically, a wetland must have at least one of the following attributes:

> "(1) At least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin et al. 1979).

The ecological, economic, and recreational values of this habitat type cannot be overemphasized. Wetland systems are critical to flood and erosion control, recharging aquifers, and water purification. They are among the most productive ecological systems (Weller 1986). This inherent productivity supports a diverse wildlife and fish community including many species of nongame birds, furbearers, and waterfowl, plus threatened and endangered species. Commercial fisheries, furbearer harvest, nonconsumptive recreation and study, waterfowl hunting, and recreational fishing are examples of the diverse commercial and recreational opportunities supported by this single habitat type.

The productive capacity of wetland soils is, ironically, partially responsible for wetland destruction. Dynamic processes at the land-water interface and the anaerobic conditions of the substrate are responsible for large accumulations of organic matter and associated nutrients resulting in sites with very high productivity potential. This aspect of wetlands attracts land uses that can conflict with maintaining the biological integrity of wetland systems. Cattle grazing, timber harvesting, and tillage have all contributed to the degradation and destruction of wetland habitats when managed to the exclusion of other uses. Clearly, the productivity of wetlands targets this habitat type as an area of high resource conflict—a particularly important characteristic given the increasing rarity of wetlands.

Every state contains some wetland habitat; however, wetlands across the nation only account for about 5% of the land area within the lower 48 states, or approximately 99 million acres in the mid-1970's (Tiner 1984). Palustrine (i.e., inland shallow water) wetlands with woody vegetation comprise the majority of extant wetland habitats with 61% classified as forested or scrub-shrub wetlands (fig. 3). Although estimates of original wetland area are difficult to determine, Roe and Ayers (1954) estimated that the conterminous United States had 215 million wetland acres before settlement. If this estimate is accurate, then wetland acres have declined by 54%.

Frayer et al. (1983) completed a more recent study of wetland trends between the mid-1950's and the mid-1970's. Although some less productive wetland types had modest gains, total wetland area declined substantially (table 7).

Approximately 193,000 acres of unvegetated palustrine flats and 2.1 million acres of ponds were created from 1954 to 1974. Pond acres (palustrine open water) nearly doubled and were attributed to farm pond construction between the Rocky Mountains and the western border of the Atlantic coastal states. Most of these acres were formerly upland sites; however, 25% of the converted acres came from flooding forested and emergent wetlands (Tiner 1984).

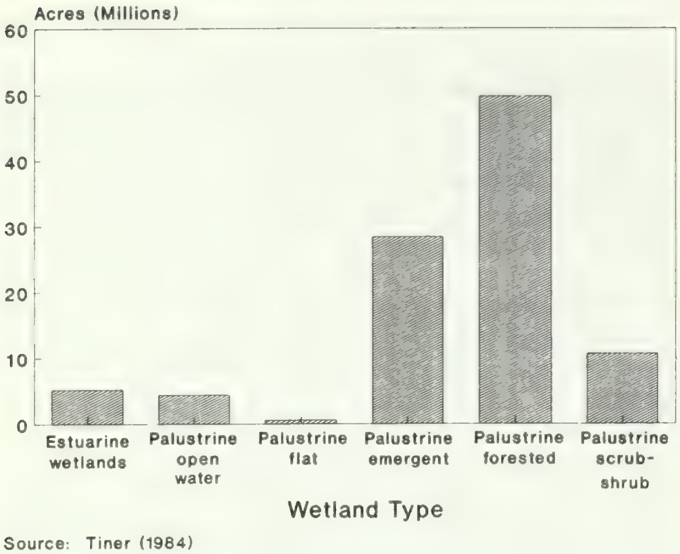


Figure 3.—Distribution of wetland acres by wetland type.

Apart from these gains, all other wetland types declined dramatically. Total wetland area declined from 108.1 million acres in 1954 to 99 million acres in 1974 for an average loss rate of 458,000 acres per year. Acres lost varied by wetland type; forested wetlands declined by nearly 11%; emergent wetlands declined by 14%; scrub-shrub wetlands declined by 3.5%; and estuarine wetlands declined by 6.5%. Draining and tillage was responsible for 87% of the lost wetland acres, while urban development (8%) and other development (5%) were relatively minor factors in the wetland decline.

Agricultural and urban impacts on wetland habitats are most conspicuous in on-site development activities. However, land-use practices, municipal uses, and human alteration of water courses and ground water hydrology have had less conspicuous but equally detrimental off-site impacts (Cowan and Turner 1988, Weller 1988). Increased water withdrawals have lowered water tables and altered salinity concentrations on a landscape scale which affects plant species composition and contaminates public water supplies. Increased sediment loads from agricultural erosion have buried many aquatic grass beds. Channelization and levee construction have significantly altered the natural marsh building processes in estuarine systems. Protection and restoration of wetland habitats must recognize and address the cumulative effects of both on-site and off-site impacts stemming from human land management activities.

The distribution of wetland acres varies by geographic region and is a function of climate, geology, soils, and past land-use practices. Although only 5% of the land area in the lower 48 states is classified as wetland, wetlands comprise a significantly greater proportion of the land base in certain areas (fig. 4). Two important assessment regions regarding wetland area are the South, and the north-central portion of the North. In Alaska alone, it has been estimated that about 55% of the state's area is classified as wetland (Akins 1982, Saling n.d.).

Although comprising a much smaller component of the land base in other assessment regions, wetlands retain their value and importance to wildlife and fishery habitat. Riparian habitats in the arid portions of the Rocky Mountain region provide critical habitat for the native fauna (Hubbard 1977). Disruption and elimination of stream flows are responsible for the loss of riparian habitat. Similarly, grazing has greatly reduced the quality of regional riparian areas (Swift 1984).

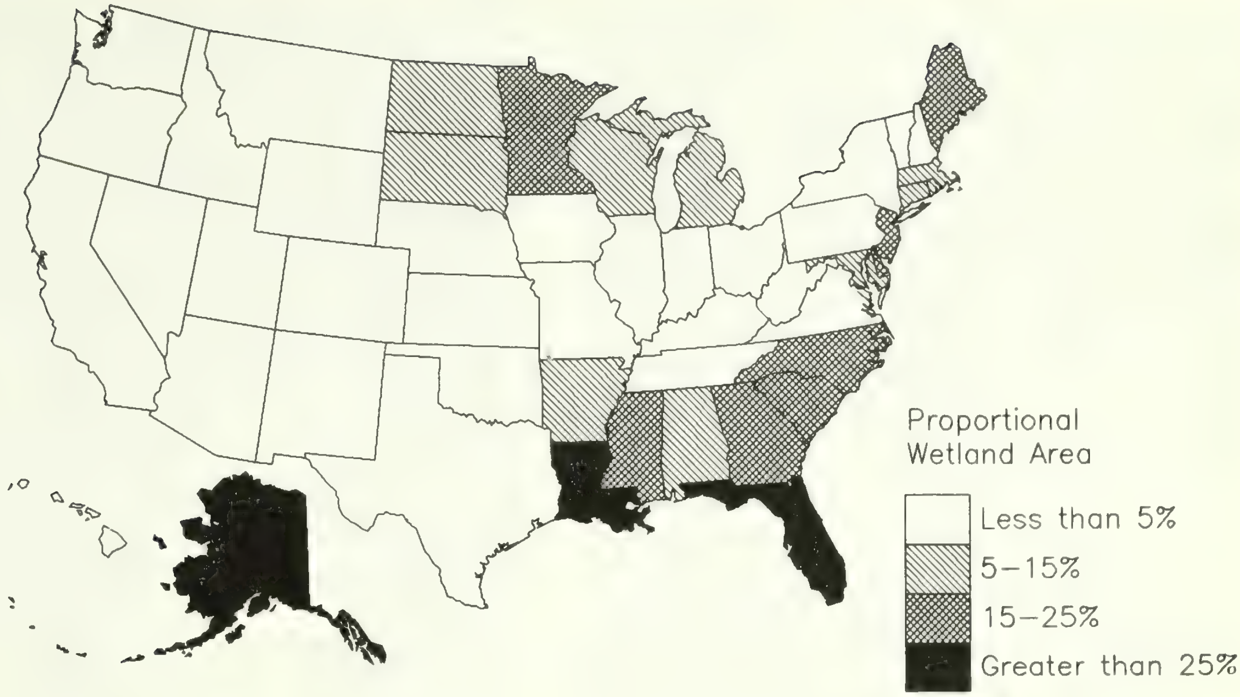
Noted loss rates at the national level are magnified when examined at the regional or state level. Recently published statistics on the amount of wetland habitat lost show that declines ranged from 99% for Iowa natural marshes to 32% for Wisconsin wetlands (Tiner 1984).

Much of these losses can be attributed to destruction that occurred by the turn of the century—destruction motivated by legislation which encouraged drainage of wetlands for agricultural development (e.g., the Swamp Lands Acts of 1849, 1850, and 1860). However, evidence suggests the rate of wetland habitat destruction has remained high in more recent times. As reviewed by Tiner (1984), Illinois was losing approximately 2% of its wetlands annually as of 1981; Kansas lost 40% of its wetlands from 1955 to 1978; half the wetlands along Ohio's Lake Erie coast have been destroyed; and Kentucky wetlands have been reduced by 37% along the Mississippi and Ohio River Valleys.

Table 7.—Area of wetland types for the conterminous United States in 1954 and 1974.

Year	Estuarine wetland	Palustrine Open water	Flat	Emergent wetland	Scrub-shrub wetland	Forest wetland
				Thousand acres		
1954	5,609	2,320	384	33,113	10,998	55,707
1974	5,242	4,393	577	28,442	10,611	49,713
Change	–367	2,073	193	–4,671	–387	–5,994

Source: Frayer et al. (1983), Tiner (1984).



Source: Tiner (1984)

Figure 4.—Distribution of wetland acres by state.

Based on these findings, Tiner (1984) identified nine national wetland problem areas. These represent areas under the greatest threat of continued degradation and should receive primary consideration in future actions to protect and manage this vanishing habitat type. The problems areas include: (1) Estuarine wetlands of the U.S. Coastal Zone, (2) Louisiana's coastal marshes, (3) Chesapeake Bay's submergent aquatic beds, (4) South Florida's palustrine wetlands, (5) the Prairie Pothole Region's emergent wetlands, (6) Wetlands of the Nebraska Sandhills and Rainwater Basin, (7) Forested wetlands of the Lower Mississippi Alluvial Plain, (8) North Carolina's pocosins, and (9) Western riparian wetlands. The distribution of these nine problem areas by assessment region shows that the South incurs the greatest number of wetland-associated conflicts. The Rocky Mountain region also suffers high wetland conflict due to the loss of riparian and pothole wetlands.

These observed wetland declines negatively impact wildlife and fish resources. Although the flooding of upland sites may provide new habitats for ducks and other shallow-marsh birds (National Academy of Sciences, National Research Council 1982), these benefits will be completely masked by the detrimental effects associated with the drainage and development of extant wetland. Because of their recreational and economic importance, and because they depend on wetlands, waterfowl are emphasized as a species category that is particularly impacted by wetland loss. However, waterfowl may be more appropriately regarded as indicators of wetland fauna, for dwindling waterfowl populations may be the first conspicuous indication of a damaged or degenerating wetland. Both breeding habitat in the North, a major portion of which is in Canada, and wintering habitat in the South and Mexico are being lost. The geographic dispersal of habitat used seasonally by wetland species emphasizes the importance of international cooperation in conserving wetlands. This concern has recently been recognized in the approval of the North American Waterfowl Plan by the United States and Canada (USDI Fish and Wildlife Service, and Canadian Wildlife Service 1986a). Efforts are also underway to include Mexico in this cooperative management plan.

Flowing Waters and Associated Impoundments

Information on the nation's fisheries habitat have been surveyed recently by the Fish and Wildlife Service as part of the National Fisheries Survey. The information reported here, except as cited, is a synthesis of that study as reported by Judy et al. (1984). The survey is based on a nationwide statistical sample of 1,303 stream reaches. A more detailed analysis of recent trends in water quantity and quality is reviewed by Guldin (in press).

Two major objectives of the survey were to identify the extent of the nation's stream fishery resources and to identify those factors which adversely affect those resources. Based on the survey, 69% of the streams contained year-round fish habitat, 17% provided habitat seasonally, primarily from March through June, and 14% provided no fish habitat. Although the nation's fishery is extensive, study results also indicated that 80% of the nation's streams have problems with water

quantity, water quality, fish habitat, or fish communities. Water quantity was a problem in 68%, water quality in 56%, fish habitat in 49%, and problems with fish communities in 32% of the streams sampled. In all cases land-use intensification (i.e, agricultural or urban development) was a prominent factor in the implied deterioration of aquatic habitats.

If low flows resulting from natural conditions are disregarded, then diversions for agricultural uses were the most important contributor to water quantity problems (table 8). Other sources of water quantity problems attributed to intensified land use include dam construction for water storage, flood control, and power generation. Considered as a group, dams were responsible for water quantity problems in 9% of the streams sampled. In a more recent analysis of the nation's water quantity situation, Guldin (in press) cites that between 1960 and 1985 total water surface withdrawals increased 55% while human populations increased only 32%—a per capita increase of 16%. Agricultural uses, primarily for irrigation, accounted for the largest amount of withdrawals.

Water quality factors that accounted for over 90% of the problems limiting fishery resources, in order of importance, were turbidity, high temperature, nutrient surplus, toxic substances, and dissolved oxygen (table 8). These problems frequently exist in various combinations to compound the effect on fish communities. The five most important sources of the water quality problems were nonpoint sources (38%), agricultural sources (30%), natural sources (22%), point sources (12%), and logging (8%).

Although water quality problems associated with acid deposition were not directly assessed by Judy et al. (1984), they can be inferred from pH factors. At a pH less than 5.0, most clear lakes do not support game fish. Low pH (too acidic) was a problem in only 2.6% of the water bodies sampled. In a separate study, the USDC National Technical Information Service (1987) found three subregions where lake acidity problems were most prominent. These subregions included the Adirondacks and Michigan's Upper Peninsula where up to 2% of the lake area had pH values less than 5.0. Twelve percent of Florida's lakes were acidic, but many Florida lakes are naturally acidic.

A recent report by the Environmental Protection Agency supports the findings of Judy et al. (1984) regarding the relative importance of nonpoint and point sources of pollution. In a summary of state water quality reports that are required by the Clean Water Act, the Environmental Protection Agency (1987) found that about 25% of the nation's stream miles, lake acreage, and estuarine acreage were not fully supporting the uses designated for those water bodies. Of the waters with impaired use, nonpoint-source pollution was responsible in 76% of lake acres, 65% of stream miles, and 45% of estuarine acres. Conversely, point-sources of pollution were responsible in 9% of lake acres, 27% of stream miles, and 34% of estuarine acres.

The relative importance of nonpoint and point sources of pollution appears to have shifted since the last assessment (Guldin in press). Between 1974 and 1984, Smith et al. (1987) found widespread decreases in fecal coliform bacteria and lead concentrations, and to a lesser extent, phosphorous concentrations—all of which can be traced to control of point-source pollution. They also found evidence that nitrate, chloride, arsenic, and cadmium concentrations (pollution traceable to nonpoint sources) showed widespread increases. So while some aspects of water quality are improving, realizing further improvement will require the more difficult task of controlling nonpoint pollution.

Table 8.—Sources of water quantity problems and water quality factors adversely affecting the nation's fisheries.

Source/factor	Stream miles	Percentage
Source of water quantity problems		
Natural low flows	477,791	50.1
Diversions (agricultural)	130,223	13.6
Dam(s) (water storage)	32,901	3.5
Dam(s) (flood control)	28,002	2.9
Dam(s) (power)	24,821	2.6
Other	18,851	2.0
Diversions (municipal)	10,694	1.1
Channelization	10,629	1.1
Flood/low flows	10,527	1.1
Irrigation	8,897	0.9
Logging	6,271	0.7
Ditches	5,335	0.6
Diversions (industrial)	3,292	0.3
Water quality factors		
Turbidity	328,261	34.4
High water temperature	250,187	26.2
Nutrient surplus	119,519	12.5
Toxic substances	93,603	9.8
Dissolved oxygen problem	91,022	9.5
Nutrient, deficiency	40,603	4.3
Low water temperature	29,877	3.1
Other	26,685	2.8
pH too acidic	24,793	2.6
Low flow	24,364	2.6
Salinity	17,217	1.8
Sedimentation	14,378	1.5
Siltation	9,644	1.0
Gas supersaturation	5,500	0.6
Intermittent water	4,839	0.5
Herbicides and pesticides	4,356	0.5
pH too basic	3,998	0.4
Channelization	2,937	0.3

Source: Judy et al. (1984).

The National Fishery Survey identified two specific fish habitat components which, when lost, most adversely affect fish communities. They are juvenile/adult and egg/larva habitats, accounting for 40% and 28% of stream miles sampled, respectively. Overhead cover was found to be inadequate in 14% of the streams. These habitat problems were caused by siltation (28% of the stream miles), bank erosion (18%), natural causes (18%), channelization (12%), and migration blockage (5%).

Factors that directly impacted fish communities included fish kills, contamination of fish flesh, overharvest, disease, and parasites. Fish kills were found to be a problem in 15% of the nation's streams, while

contamination and overharvest (including poaching) were a concern in 9% and 7% of the streams, respectively. Natural causes (e.g., low flows that result in lethal water temperatures), pesticides, and other toxic or noxious substances were the three most prevalent causes of fish community problems.

In most cases, the net result of problems with water quantity or quality, or with specific fish habitat characteristics is not a complete elimination of fish but an alteration of species composition. Citing the over-reliance on water quality measures to evaluate aquatic habitats, Karr (1981) developed a fish community index of biological integrity to improve on past habitat assessments. Applications in the Midwest (Karr 1981, Karr et al. 1986) have quantified the negative impacts associated with urban and agricultural development which result in lower species diversity, a dominance of pollution-tolerant species and habitat generalists, and a higher proportion of diseased fish. Although the technique has been adapted to other regions outside the Midwest, regional application of the technique needs further refinement and testing (Miller et al. 1988).

Agricultural Habitats

Agricultural land differs in a very basic sense from the other habitat types discussed. Agriculture is typically thought of as a disturbance to natural plant and animal communities. However, agriculture is such an expansive modification process that attributes associated specifically with agricultural land can be evaluated as either beneficial or detrimental to wildlife and fish habitat.

Cropland acres, in recent history, have been relatively stable. After reaching a low in 1969, cropland began increasing in response to escalating world demand and market trends (fig. 2). Cropland is not evenly distributed across the nation. In 1981, the North accounted for about 36% of the total cropland area while the Pacific Coast only accounted for 6% (table 9).

Trends in cropland by assessment region are consistent with the national trend (table 9). Between the late 1940's and early 1970's, the acreage of land in crops declined in all regions. Cropland acres during the next 10 years increased and exceeded the acres cropped in 1949 in all regions except the South.

In addition to agricultural land area changes, the productivity of harvested lands has increased through the uses of pesticides, fertilizers, improved seeds, and advances in farm machinery and irrigation (The Conservation Foundation 1984). Agricultural intensification has caused changes in farm numbers, farm size, field size, and land in permanent vegetative cover including shelterbelts, hedgerows, and field borders. Changes in these farm land characteristics are what impact those wildlife and fish species associated with agricultural habitats.

The number of farms is inversely related to the size of farms. Since 1945, the number of farms has declined by nearly 60%. Over the same period, farm size has increased by over 120% with the largest gain occurring in the South (Council on Environmental Quality 1985). Farm production and management has become concentrated among fewer and larger farms. Attendant with these noted changes in farm size has been a trend toward larger field size and reduced crop diversity. Larger fields and regional specialization in one or two crops have been necessary to capture the efficiency of large farm equipment (Burger 1978).

Collectively, these changes in farming technique and practices have encouraged the elimination of wildlife and fish habitat. The removal of hedgerows, field border strips, wetlands, and woodlots to maximize crop production has reduced the amount of vertical and horizontal habitat diversity and with it the last remaining wildlife habitat in agriculturally dominated landscapes (Burger 1978, Office of Technology Assessment 1985). Since 1950, the amount of farm land in woodlots has declined by over 50% (fig. 5). Fencerow-to-fencerow farming has eliminated much of the nesting, feeding, and winter wildlife cover associated with agricultural land use (Carlson 1985).

Many wildlife species are adapted to agriculturally dominated landscapes. Upland game including northern bobwhite, ring-necked pheasant, and cottontail rabbit commonly utilize habitat associated with agricultural land. Recent trends in these species' populations and harvests indicate increasing agriculture-wildlife

Table 9.—Trends in cropland use for crops by assessment region.

Region	1949	1972	1981
	Thousand acres (% of total)		
North[1]	133.4 (34)	117.4 (35)	141.4 (36)
South[1]	103.8 (27)	73.9 (22)	91.8 (24)
Rocky Mountain	128.6 (33)	122.2 (37)	131.6 (34)
Pacific Coast[2]	20.8 (5)	20.0 (6)	22.1 (6)

[1]*West Virginia is included in the South instead of the North.*
[2]*Does not include Alaska or Hawaii.*
Source: Frey and Hexem (1985).

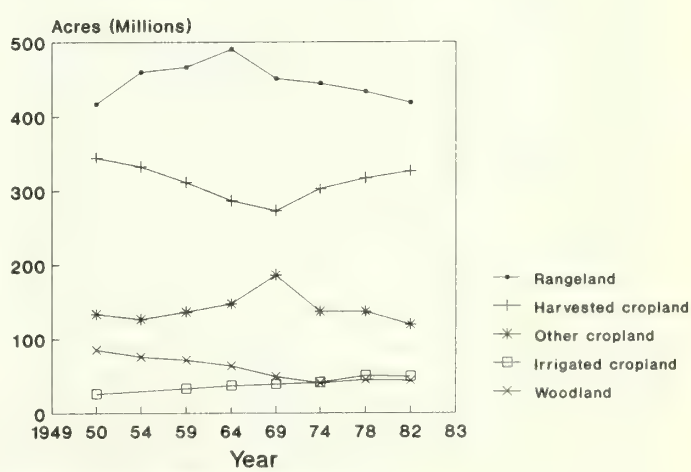


Figure 5.—Historical uses of farmland area from 1950–1982.

conflicts. Brady (1985) found a statistically significant correlation between increasing acres in row crops and reduced harvests of pheasant, quail, and rabbit in Illinois. Similar declines in other farm-associated wildlife have been noted over their entire range (Berner 1984, Farris and Cole 1981).

Not all agriculture-related wildlife and fish impacts occur or remain on site. Soil erosion degrades stream habitats and has resulted in the loss of native fish species (Menzel 1983). Nonpoint chemical pollution from cropland has also been implicated as a contributing factor in the decline of striped bass (Fosburgh 1985a). In general, wildlife and fish managers are seeing an overall decline in all species associated with agricultural lands (Carlson 1985).

The noted national and regional trends in agriculture have recently had negative impacts on wildlife and fish communities. Subsequent sections in this report concerning populations and harvests will further document the declining value of agricultural lands as wildlife habitat. Although federal agencies have been promoting conservation practices that would reduce wildlife and fish habitat impacts (see Office of Technology Assessment 1985), recent levels of implementation have not been sufficient to reverse declining habitat quality.

Summary

Current and recent historical trends in wildlife and fish habitats reflect, in part, national and regional policies concerning the use of forest, range, and agricultural lands. National trends in these major land-use types showed relatively minor changes in the last 20 years. Because net land area dynamics were small, evaluating land-use impacts on wildlife and fish habitat required examining characteristics within each land-use category that affect habitat quality.

Forest changes in the East showed major declines in Southern pine types, bottomland hardwoods, aspen-birch, and elm-ash-cottonwood. Changes in forest successional stages (as measured by stand-size class) were related to timber demands. Mature and old-growth softwood stands are becoming increasingly rare in the major timber producing regions of the Pacific Northwest and South. Commercial demand for eastern hardwoods has not kept pace with forest growth, allowing a greater acreage of older hardwood stands in the North.

Rangeland wildlife habitats are affected importantly by the levels of grazing and management practices directed toward increasing livestock production. Livestock numbers have been recently declining, probably because of low prices and reduced human diet preference for red meat. With the declining number of livestock, the potential exists for increased quality of rangeland environments for wildlife and fish. Two issues that remain important are the reduction in total area and fragmentation of grassland habitats in the East, and degradation of riparian habitats in the arid West.

Agricultural development is an important modifier of natural environments. Although cropland area has increased in the recent past, the most important changes related to wildlife and fish habitat are more intensive farming practices and larger farm size. This intensification has eliminated or reduced the size and frequency of shelterbelts, field borders, hedgerows, and odd habitat areas that were previously inconvenient to crop. Similarly, wetland habitats have declined and other aquatic environments have witnessed degradation in quality as agricultural land-use has intensified.

Finally, urban and suburban land uses have been increasing in response to growing human populations. Urban development not only removes land directly from natural vegetation conditions, it increases human-related disturbance on remaining fragments of habitat and the wildlife and fish inhabiting them.

Land-use and land-cover patterns provide a coarse description of wildlife and fish habitats that is appropriate for national and regional evaluations. The amounts and characteristics of the various land types discussed above are the ultimate basis for the kinds and quality of habitat available to wildlife and fish. The wildlife and fish populations, number of users, and harvests supported by these habitats are the subject of the next section of this report.

Wildlife and Fish Population, Use, and Harvest Trends

Recent trends in populations, number of users, and harvests of wildlife and fish are derived from a data base that was compiled in cooperation with state and federal wildlife agencies. In some cases, these data were available for a long series of years for a particular species; in other cases, data were available for only a few years in a few states. Harvest and use data were more generally available than were estimates of populations, and population data for game species was more complete than for nongame wildlife. The wildlife and fish species groups that have been used in this assessment are a result of available information and it must be realized that the estimates reviewed, in many cases, are the best judgments of qualified professional wildlife and fisheries biologists. Consequently, the actual magnitude of the estimates is less important than the trend.

Nongame Wildlife

For the purposes of this report, nongame is defined as those native vertebrate species that are not consumptively taken for sport, fur, food, or profit. As such, nongame constitutes a majority of the approximately 3,000 vertebrate species that are resident or seasonal inhabitants within the United States. Although threatened and endangered species are included in nongame by this definition, a more detailed discussion of threatened and endangered species is covered in a later section of this chapter.

Populations.—Very little information exists on the status of nongame wildlife populations at a geographic scale that would permit evaluation of national or regional population patterns. Part of the reason for this

limited information base is the historical emphasis that state and federal wildlife managing agencies have placed on documenting game species populations for management purposes (Cerulean and Fosburgh 1986). In addition, the magnitude of a complete national inventory of nongame species would be prohibitively expensive and impracticable. Many of the species are difficult to monitor because of their secretive habits (Miller 1984).

One species group where sufficient population information exists to support an analysis of nationwide abundance patterns is birds. Systematic surveys conducted during breeding, migration, and winter seasons provide useful data sources. The Fish and Wildlife Service administers the Breeding Bird Survey (BBS) which is based on randomly distributed roadside routes within each one degree block of latitude and longitude (Robbins et al. 1986). This survey is designed to assess the population trends of breeding birds in the United States and southern Canada. However, not all species are adequately represented by the BBS. Erskine (1978) noted the shortcomings of the BBS when the species are nocturnal, wide-ranging, or flocking.

The Conservation Foundation (1984) reported on the trends in the BBS from 1968 through 1981 for 552 species. Their summary indicated that 66 (12%) species had increasing populations, 46 (8%) had decreasing populations, 298 (54%) had no statistically significant trend, and 142 (26%) had a sample too small for analysis. More recent trend analysis results from 1966–1987 (Droege, pers. comm., 1988) revealed that 18% of the bird species sampled had increasing populations, 13% were decreasing, 39% had no significant trend, and 30% had an insufficient sample size.

Although these BBS trend analyses provide evidence that the majority of breeding bird populations have remained stable since the mid-1960's, a significant proportion of the breeding bird fauna has declined over a 20-year period. Species that have shown significant declining trends varied by region owing to differences in species distribution, climate, and land use (table 10). The regional boundaries in this case are those defined by the Fish and Wildlife Service. The Eastern Region includes all states east of the Mississippi River; the Central Region is comprised of states between the Rocky Mountains and Mississippi River; and the Western Region extends from the Rocky Mountains to the Pacific Coast. Progressing from East to West, one encounters fewer species with significantly declining populations. This suggests the East's greater human population and associated human activity have contributed to eastern birds' decline.

The factors explaining these trends are in most cases unknown. As reported by Robbins et al. (1986), habitat gain was the most common reason for 10 cases of population growth. Increases in available habitat was associated with species that were adapted to urban environments and the use of human structures for nest sites (e.g., barn swallow, cliff swallow, and house finch). Other reasons cited for expanding breeding populations included reductions in the use of organochlorine pesticides and increases in food sources associated with insect outbreaks. The red-eyed vireo, warbling vireo, worm-eating warbler, blue-winged warbler, Tennessee warbler, and American robin are examples of species that have likely responded positively to reduced pesticide usage and an outbreak of spruce budworm in the East.

More cases of decreasing populations of breeding birds were attributed to specific environmental factors. Of the 23 reasons cited by Robbins et al. (1986), the most common was severe winter weather conditions during the mid to late 1970's which increased the mortality of eastern phoebe, winter wren, Bewick's wren, and song, field, and white-throated sparrows. Loss or degradation of habitat was a factor cited in the decline of loggerhead shrike, prairie warbler, yellow-breasted chat, and lark bunting. Interspecific competition involving starlings was also an important factor contributing to the decline of several cavity-nesting species including the eastern bluebird and northern flicker. Although weather and habitat factors are discussed independently, their influence on wildlife populations cannot be separated. While harsh weather may have been the direct cause of population declines, insufficient cover or food has likely predisposed individuals to increased mortality during extreme weather events.

Raptors are a particularly unique bird group that is not well represented in the breeding bird survey. Their positions at the top of their food chains make them important indicators of environmental change. The plight of certain raptor populations during the 1960's and 1970's provided a focal point for the environmental movement and brought about regulations and intensive management that has resulted in significant recovery of several species.

Evans (1982) evaluated the status of 12 raptor species that were characterized by either recent population declines or had inconclusive evidence concerning population change. The 12 species included: bald eagle, burrowing owl, crested caracara, Cooper's hawk, ferruginous hawk, northern harrier, merlin, northern aplomado falcon, osprey, peregrine falcon, prairie falcon, and sharp-shinned hawk. Half of these species appear to be recovering from recently observed declines. The bald eagle, Cooper's hawk, osprey, peregrine falcon, merlin, and sharp-shinned hawk have responded favorably to U.S. restrictions in the use of organochlorine pesticides. Continued use of pesticides in South and Central America, however, has the potential to counteract the gains that have recently been observed.

Three raptor species have continued to decline over their ranges, primarily owing to lost critical habitat elements. The crested caracara has suffered from the clearing of chaparral brushlands (Porter and White 1977) and the conversion of native prairies and pastureland to urban and agricultural development (Paradiso 1986). The elimination of burrowing rodents has dramatically reduced the available habitat for burrowing owls. The northern aplomado falcon has declined due to encroachment by creosote and mesquite on the preferred grassy plains and savanna habitats, and continued use of organochlorine pesticides in Mexico (USDI Fish and Wildlife Service 1986b).

Table 10.—Nongame breeding birds with significant declining trends from 1966–1987.

Eastern	Central	Western	Continental
Little Blue Heron	Northern Harrier	Turkey Vulture	Northern Harrier
Common Tern	Sharp-shinned Hawk	Northern Goshawk	American Avocet
Black Tern	Ring-billed Gull	American Avocet	Lesser Yellowlegs
Black Skimmer	Black Tern	Caspian Tern	Black Tern
Common Ground-Dove	Ladder-back. Woodpecker	Black Tern	Common Ground-Dove
Common Nighthawk	Northern Flicker	White-throated Swift	Belted Kingfisher
Chuck-will's-widow	Eastern Wood-Pewee	Ladder-back. Woodpecker	Red-headed Woodpecker
Chimney Swift	Acadian Flycatcher	Northern Flicker	Sapsucker species
Red-headed Woodpecker	Vermilion Flycatcher	Olive-sided Flycatcher	Ladder-back. Woodpecker
Sapsucker species	Black-billed Magpie	Horned Lark	Northern Flicker
Northern Flicker	Verdin	Pinyon Jay	Olive-sided Flycatcher
Olive-sided Flycatcher	Cactus Wren	Black-billed Magpie	Eastern Wood-Pewee
Eastern Wood-Pewee	Bewick's Wren	Yellow-billed Magpie	Vermilion Flycatcher
Least Flycatcher	Veery	Black-capped Chickadee	Scissor-tail. Flycatcher
Eastern Phoebe	Wood Thrush	Golden-crowned Kinglet	Gray Jay
Gray Jay	Northern Mockingbird	Veery	Blue Jay
Blue Jay	Brown Thrasher	Brown Thrasher	Pinyon Jay
Boreal Chickadee	Curve-billed Thrasher	California Thrasher	Black-billed Magpie
Bewick's Wren	Loggerhead Shrike	Sprague's Pipit	Boreal Chickadee
Ruby-crowned Kinglet	White-eyed Vireo	Loggerhead Shrike	Golden-crowned Kinglet
Veery	Bell's Vireo	Chipping Sparrow	Veery
Wood Thrush	Northern Parula	Clay-colored Sparrow	Wood Thrush
Gray Catbird	Yellow Warbler	Black-chinned Sparrow	Northern Mockingbird
Northern Mockingbird	Prairie Warbler	Song Sparrow	Brown Thrasher
Brown Thrasher	Prothonotary Warbler	White-crowned Sparrow	Curve-billed Thrasher
Loggerhead Shrike	Worm-eating Warbler	Bullock's Oriole	California Thrasher
European Starling	Ovenbird	House Finch	Sprague's Pipit
Golden-winged Warbler	Kentucky Warbler	White-winged Crossbill	Loggerhead Shrike
Prairie Warbler	Hooded Warbler		European Starling
Bay-breasted Warbler	Pyrrhuloxia		Bell's Vireo
Cerulean Warbler	Painted Bunting		Golden-winged Warbler
Common Yellowthroat	Cassin's Sparrow		Prairie Warbler
Yellow-breasted Chat	Brewer's Sparrow		Bay-breasted Warbler
Northern Cardinal	Field Sparrow		Cerulean Warbler
Indigo Bunting	Lark Sparrow		Kentucky Warbler
Painted Bunting	Black-throated Sparrow		Yellow-breasted Chat
Dickcissel	Lark Bunting		Northern Cardinal
Rufous-sided Towhee	Grasshopper Sparrow		Pyrrhuloxia
Field Sparrow	Bobolink		Indigo Bunting
Vesper Sparrow	Western Meadowlark		Painted Bunting
Savannah Sparrow	Orchard Oriole		Rufous-sided Towhee
Grasshopper Sparrow	House Sparrow		Cassin's Sparrow
Henslow's Sparrow			Clay-colored Sparrow
Song Sparrow			Field Sparrow
White-throated Sparrow			Black-chinned Sparrow
Red-winged Blackbird			Lark Sparrow
Eastern Meadowlark			Lark Bunting
Western Meadowlark			Baird's Sparrow
Rusty Blackbird			Grasshopper Sparrow
Common Grackle			Henslow's Sparrow
Brown-headed Cowbird			Song Sparrow
American Goldfinch			White-throated Sparrow
House Sparrow			White-crowned Sparrow
			Slate-colored Junco
			Eastern Meadowlark
			Western Meadowlark
			Rusty Blackbird
			Common Grackle
			Brown-headed Cowbird
			Orchard Oriole
			Bullock's Oriole
			White-winged Crossbill
			American Goldfinch
			House Sparrow

Source: Droege, pers. comm., 1988.

Because of inadequate information, the status of the ferruginous hawk, northern harrier, and prairie falcon is unclear. Although there is little population information on these species, loss of habitat is generally suspected. Alteration of the semi-arid western plains habitat (ferruginous hawk), drainage of wetland habitat (northern harrier), and agricultural development, water impoundments, and pest control in the arid West (prairie falcon) have all been implicated as prime factors for the decline of these species in portions of their range (Evans 1982).

A primary objective of the various monitoring programs conducted by the Fish and Wildlife Service is to detect trends in bird populations early so that appropriate management or regulations can be implemented before population levels become critically low. In an effort to consolidate the findings from various bird monitoring efforts, and to isolate the causes for bird population declines, the Fish and Wildlife Service has developed criteria for the identification of birds with declining or unstable populations nationwide over the last 10–15 years (USDI Fish and Wildlife Service 1982a). The identification of species was based on several sources including the BBS, state endangered and threatened species listings, National Audubon Society's Blue List, Office of Endangered Species "Watchlist," and expert opinion. Of the 237 nominated species, 28 species were identified as exhibiting unstable or declining populations (table 11). The distribution of these 28 species across assessment regions is surprisingly even with 15 species occurring in the North, 14 in the South, 15 in the Rocky Mountain, and 10 in the Pacific Coast.

Taxonomically, most of the species are marsh or wading birds, followed in rank order by passerines, birds of prey, shorebirds, and marine birds (fig. 6). On the basis of habitat, species associated with wetlands dominate the list (fig. 6). The next most critical habitat is grassland types followed by open woodland or forest species, and mixed habitats.

Factors contributing to the decline in these bird populations have been difficult to determine, and therefore conclusions are based on the collective impressions of experts (USDI Fish and Wildlife Service 1982a). Without question, the primary cause cited for population declines is the loss or degradation of breeding, feeding, or wintering habitat (fig. 7). The pattern of habitat loss discussed earlier gave presage to the distribution of species by habitat type. The destruction and development of wetland habitats was the major concern for those species listed. Increased loss of grasslands due to agricultural development or natural succession from farm fields to forestland is also of major concern. The harvesting

Table 11.—Nongame migratory bird species with unstable or decreasing trends.

Species	Assessment region where status is of concern				Primary reason for listing		
	North	South	Rocky Mountain	Pacific Coast	Apparent population decline	Small population size	Restricted habitat
Common Loon	X				X		
Reddish Egret		X	X			X	X
Least Bittern	X	X	X	X	X		X
American Bittern	X				X		X
Wood Stork		X			X		X
White-faced Ibis			X	X		X	X
Trumpeter Swan			X	X		X	X
Red-shouldered Hawk	X				X		X
Ferruginous Hawk			X	X	X	X	
Northern Harrier	X	X	X	X	X		X
Black Rail		X	X	X	X		X
Piping Plover	X	X	X		X		X
Snowy Plover		X	X	X	X		X
Long-billed curlew			X	X			X
Upland Sandpiper	X				X		X
Gull-billed Tern	X	X			X	X	X
Roseate Tern	X	X			X	X	X
Least Tern	X	X	X		X		X
Black Tern	X		X		X		X
Common Barn-Owl	X	X			X		X
Spotted Owl			X	X		X	X
Loggerhead Shrike	X				X		
Bell's Vireo			X	X	X		X
Golden-cheeked Warbler		X					X
Baird's Sparrow			X		X		
Henslow's Sparrow	X				X		
Seaside Sparrow		X					X
Bachman's Sparrow	X	X			X		

Source: USDI Fish and Wildlife Service (1982a).

of old-growth forests and loss of riparian woodlands are of primary concern in forested environments.

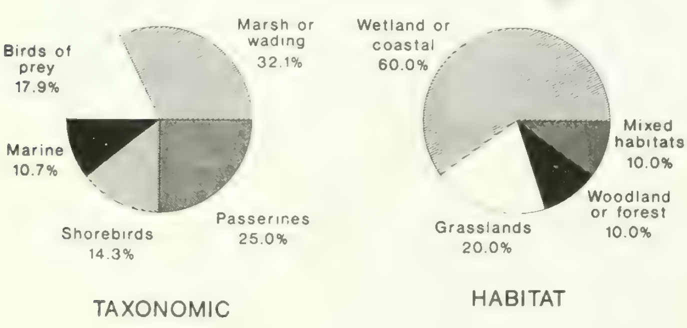
One additional characteristic associated with habitat loss is that over half (57%) of the species listed are Neotropical migrants. Not only is there concern for the loss of wetlands and deforestation in the tropics, but other factors including unregulated hunting, pesticide use, and pollution probably all interact to increase the mortality of Neotropical migrants on their wintering areas.

Restricted distribution, and therefore the vulnerability of their habitat to future disturbance, was also cited as a reason for the decline of several species classified as having unstable or declining populations. These species (reddish egret, golden-cheeked warbler, snowy plover, and roseate tern) have, in many cases, always been rare and therefore require special consideration in the prevention of future declines.

Human disturbance, recreational developments, and pesticide use are also considered factors responsible for population declines. However, of greater importance to the conservation of these species is the fact that in 31% of the cases the cause of the decline was either unknown or the species is not adequately monitored at this time. This emphasizes the need for continued research on the causes of population declines, and the development of monitoring techniques appropriate for inconspicuous species such as the American bittern, least bittern, and black rail.

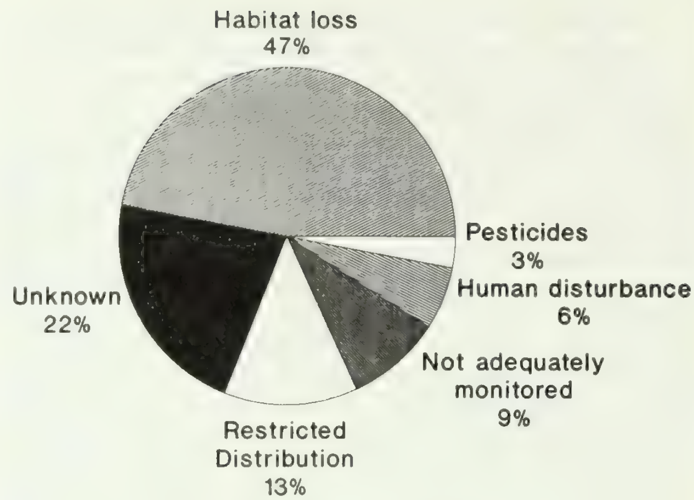
Nonconsumptive recreational use.—Nonconsumptive uses of wildlife and fish resources has been defined as those activities that do not result in the death or attempted death of an individual animal (More 1979). This definition is necessarily broad to accomodate nonconsumptive uses of both game and nongame. The findings from the 1979 national assessment (USDA Forest Service 1981) found qualitative evidence that nonconsumptive uses of wildlife and fish resources had increased greatly during the 1970's (More 1979).

Since the last RPA wildlife and fish assessment, the Fish and Wildlife Service has completed two surveys (1980 and 1985) of participation in wildlife and fish related recreation (USDI Fish and Wildlife Service, and



Source: USDI, Fish and Wildlife Service (1982a)

Figure 6.—Taxonomic and habitat characteristics of bird species listed as having unstable or declining populations.



Source: USDI, Fish and Wildlife Service (1982a)

Figure 7.—Reasons contributing to the decline in bird species listed as having unstable or declining populations.

USDC Bureau of Census 1982; USDI Fish and Wildlife Service 1988b). These two surveys permit more quantitative estimates of participation and trends in nonconsumptive activities. For the purposes of clarifying the kinds of nonconsumptive activities, four categories of use were defined (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982):

Primary, nonresidential.—Trips of at least 1 mile from place of residence for the primary purpose of observing, photographing, or feeding wildlife.

Primary, residential.—Activities around the residence for which primary purpose is wildlife related.

Secondary, nonresidential.—Enjoyment from seeing or hearing wildlife on a trip at least 1 mile from place of residence that is taken for another purpose (camping, driving, boating).

Secondary, residential.—Enjoyment from seeing or hearing wildlife while pursuing other activities around the residence.

The results from these two surveys substantiate what many have predicted to occur: wildlife-related, nonconsumptive recreational activities have become much more important to U.S. citizens in recent decades (table 12). The percentage of the U.S. population 16 years of age and older that participated in some form of nonconsumptive recreation increased from 55% in 1980 to 74% in 1985. Although both primary and secondary activities increased, secondary activities increased by a greater amount. Similarly, residential activities increased to a greater degree than nonresidential activities.

An important pattern that emerged from this comparison concerned primary nonresidential activities. This category may be thought of as a strong indicator of the public's preference for nonconsumptive wildlife-related recreation because it requires people to forgo other activities for the sole purpose of viewing, photographing, or feeding wildlife away from their residences. The number of persons participating in primary nonresidential activities increased by only 1.8% from 1980

Table 12.—Participation in nonconsumptive wildlife-related recreation from 1980–1985 for people 16 years old and older.

	Total noncon-sumptive users		Primary						Secondary					
			Total		Nonresidential		Residential		Total		Nonresidential		Residential	
Year	# in thous.	% of U.S. pop.	# in thous.	% of U.S. pop.	# in thous.	% of U.S. pop.	# in thous.	% of U.S. pop.	# in thous.	% of U.S. pop.	# in thous.	% of U.S. pop.	# in thous.	% of U.S. pop.
1980	93,249	54.9	83,173	48.9	28,822	17.0	79,670	46.9	88,272	51.9	69,407	40.8	80,475	47.4
1985	134,697	74.0	109,597	61.0	29,347	16.0	105,286	58.0	127,427	70.0	89,532	49.0	117,411	65.0

Source: USDI Fish and Wildlife Service (1988b); USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

Table 13.—Participation in nonconsumptive wildlife-related recreation by region from 1980–1985 for people 16 years old and older.

	Primary						Secondary					
	Total		Nonresidential		Residential		Total		Nonresidential		Residential	
	1980	1985	1980	1985	1980	1985	1980	1985	1980	1985	1980	1985
	Thousands											
North[1]	43,291	52,947	14,867	14,585	41,543	51,098	44,958	59,757	34,747	42,483	41,632	54,992
South[2]	22,959	35,951	6,754	8,129	22,224	35,010	24,348	42,188	18,510	27,117	22,227	39,328
Rocky Mountain[3]	4,574	6,098	2,125	2,119	4,133	5,667	4,991	7,634	4,290	6,081	4,307	6,834
Pacific Coast	12,347	14,320	5,076	4,431	11,770	13,228	13,976	17,566	11,861	13,695	12,309	16,005

[1]*Includes the states of ND, SD, KS, and NE and excludes MD, WV and DE.*
[2]*Includes the states of MD, WV, and DE.*
[3]*Excludes the states of ND, SD, KS and NE.*
Source: USDI Fish and Wildlife Service (1988b); USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

to 1985—a rate of increase that was less than the general population increase. Consequently, there was an actual decline in the proportional participation from 17% of the population in 1980 to 16% in 1985. Although changes in survey methodology are a potential source of error that may affect interpretation, these data suggest that the recent increases in nonconsumptive activities stem primarily from people becoming more aware of the associated wildlife benefits while at home or while taking part in other activities rather than from the exclusive pursuit of nonconsumptive wildlife-related recreation.

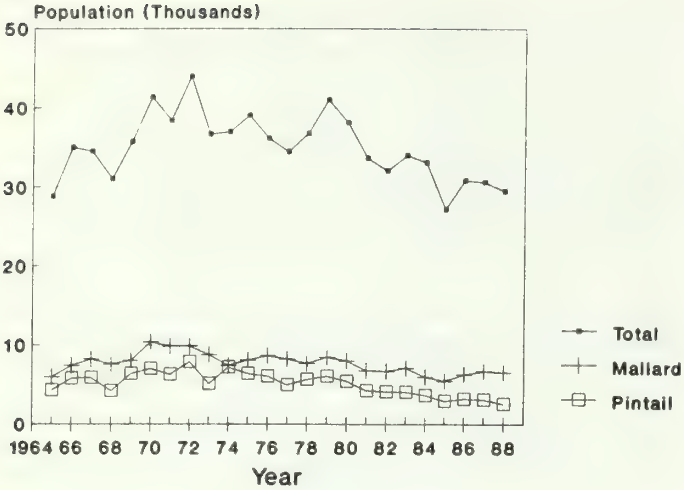
The regional trends in nonconsumptive wildlife-related recreation are generally consistent with the national trends (table 13). The Fish and Wildlife Service uses human census regions to describe regional use patterns. These regions can be aggregated to approximate the assessment region boundaries used here (see fig. 1). The greatest gains in primary and secondary nonconsumptive recreation have been in the South, which had the lowest proportional participation in 1980. The absence of significant increases in primary nonresidential participants is observed in all regions, and the absolute number of such participants actually declined in the North and Pacific Coast regions from 1980 to 1985. Significant gains in the number of participants in secondary nonconsumptive recreation were observed in all regions.

Migratory Game Birds

Migratory game birds, as defined in this report, include waterfowl (ducks, geese, and swans) along with webless migratory species such as the woodcock and mourning dove. Information on the current status of and trends in populations, harvest, and number of migratory bird hunters comes primarily from Fish and Wildlife Service annual reports.

Populations.—Waterfowl populations are one of the most significant and familiar wildlife resource legacies. Waterfowl habitats and populations reflect a long history of management concern in the United States. These concerns have been heightened recently because populations and habitat continue to decline throughout North America (USDI Fish and Wildlife Service, and Canadian Wildlife Service 1986a).

Ducks.—Although the 20-year trend in breeding populations varies depending upon the species and the geographic region being considered, notable declines have occurred in many species since the early 1970's. Breeding populations for 10 species that collectively comprise 97% or more of the breeding population in the surveyed areas (USDI Fish and Wildlife Service 1974) have declined by more than 30% since the early 1970's. After peaking around 44 million birds in 1972, populations dropped to a record low of approximately 28 million birds in 1985 (fig. 8). The two most abundant species



Source: USDI, Fish and Wildlife Service and Canadian Wildlife Service (1986b); and data on file with the USDI, Fish and Wildlife Service, Office of Migratory Bird Management

Figure 8.—Trends in total duck, mallard, and pintail breeding populations from 1965–1988.

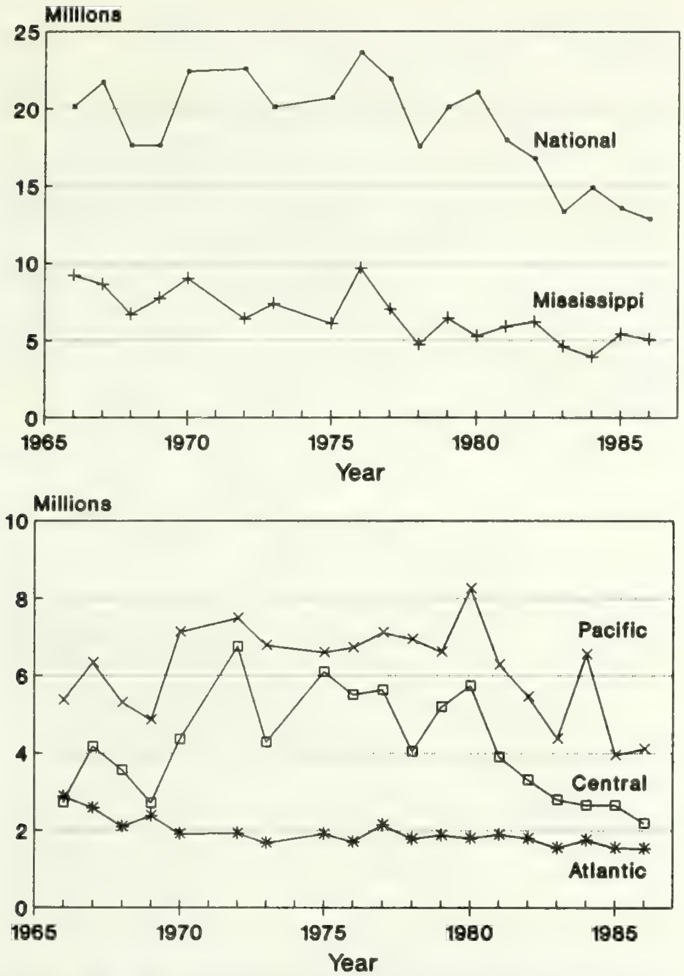
of ducks, the mallard and northern pintail, also have shown significant historical declines (fig 8). The decline has continued as the 1988 breeding populations were 20% and 54% below the 1955–1987 average, respectively. Other species that have also declined over this time period include the blue-winged teal, canvasback, and scaup. In contrast, the following species have had relatively stable or increasing populations: gadwall, American wigeon, green-winged teal, northern shoveler, and redhead.

Winter flyway surveys of ducks permit examination of recent trends on a regional basis. North American waterfowl management has been organized by flyways since 1948 and they generally represent the major pathways along which waterfowl migrate between breeding and wintering habitats. Although primarily defined by the migration routes of numerous breeding subpopulations, there are many exceptions where species migrate across flyway boundaries. Consequently, the main value of flyway management has been as an administrative tool, grouping those states together with similar waterfowl problems (Bellrose 1976). The four flyways are identified generally by the major north-south watercourses and named accordingly: Atlantic, Mississippi, Central, and Pacific (fig. 9).

The Atlantic flyway contains the smallest number of ducks. Wintering populations have shown a steady decline from about 2.9 million birds in 1966 to 1.5 million in 1986 (fig. 10). The Mississippi flyway has had the greatest number of wintering ducks, averaging about 8 million ducks annually in the late 1960's. Average winter populations dropped 35% to around 5 million by the mid-1980's. The trends in wintering ducks have been similar in the remaining two flyways—after increasing through the early 1970's, the number dropped by over 30% and 40% in the Central and Pacific flyways, respectively.

Populations of ducks found in winter flyway surveys are the product of several factors. The process begins with the number of breeding birds that flew north the previous spring, the weather during breeding, suitability of the breeding habitat, breeding success, and losses from natural and hunting mortality as the birds migrate to the wintering areas in the south. As was discussed in the habitat section, one of the most critical factors

Figure 9.—The waterfowel administrative flyways.



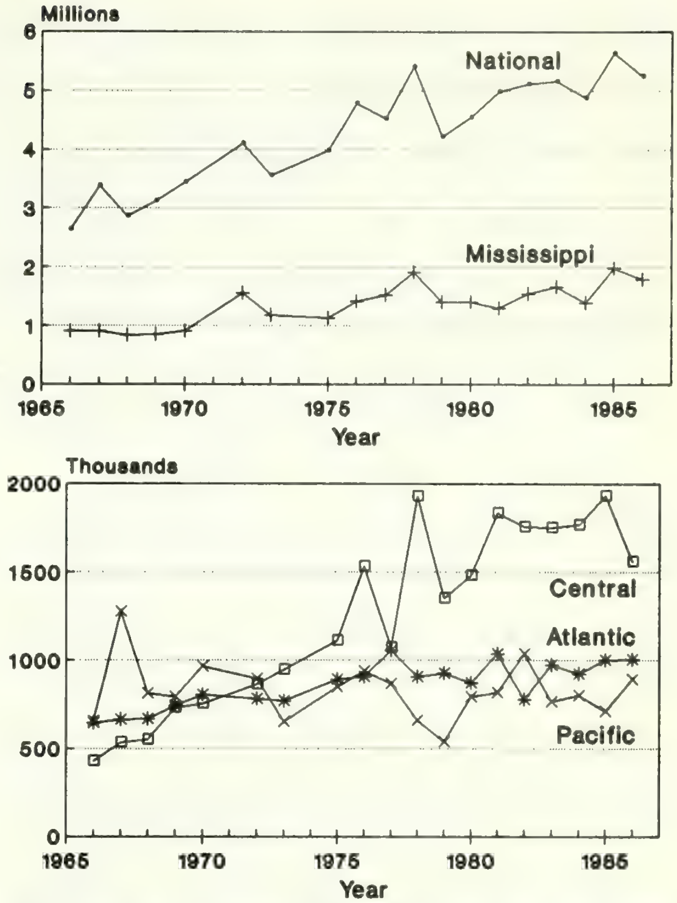
Source: USDI. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife (1966, 1967, 1968a, 1969, 1971, 1972); USDI, Fish and Wildlife Service (1975, 1980a, 1980b, 1981a, 1982b, 1987a); and data on file with the USDI, Fish and Wildlife Service, Office of Migratory Bird Management

Figure 10.—Recent historical trends in duck wintering populations for the nation and by administrative flyway.

in the equation is the amount and quality of wetland habitats (USDI Fish and Wildlife Service 1987a).

A specific habitat-quality issue that warrants discussion concerns the accumulation of toxic shot in wetland systems. Lead poisoning caused by ingestion of spent shotgun pellets inflicts significant mortality on some duck populations. The issue has been fully evaluated by the Fish and Wildlife Service; the agency has scheduled complete conversion to nontoxic shot by 1991 which should eliminate lead poisoning as a significant cause of mortality in the future (USDI Fish and Wildlife Service 1987a).

Geese.—Because most geese nest outside the breeding survey region, goose trends are based only on winter surveys. Recent trends in wintering continental goose populations have, in general, been more favorable than for ducks with most species showing stable or increasing populations (USDI Fish and Wildlife Service, and Canadian Wildlife Service 1986a). This is due, in part, to the remoteness of Arctic and subarctic breeding areas which have been isolated from extensive development



Source: USDI. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife (1966, 1967, 1968a, 1969, 1971, 1972); USDI, Fish and Wildlife Service (1975, 1980a, 1980b, 1981a, 1982b, 1987a); and data on file with the USDI, Fish and Wildlife Service, Office of Migratory Bird Management

Figure 11.—Recent historical trends in goose wintering populations for the nation and by administrative flyway.

and habitat degradation (USDI Fish and Wildlife Service 1987a). Goose populations have gone from an average of 3.0 million during 1966–1969 to an average of 5.2 million during 1982–1985 (fig. 11). Exceptions to this trend include the Aleutian, cackling, and dusky subspecies of Canada goose which have all declined due to reduced habitat, hunting (recreational and subsistence), and natural disturbance (Amaral 1985, Butler 1985, Cline and Lenhart 1985).

Wintering geese, surveyed within the same flyways as ducks, climbed steadily in the Atlantic flyway from a low of 650,000 in the mid-1960's to 1 million by 1986 (fig. 11). The Mississippi and Central flyways have typically had the greatest number of wintering geese. Populations have risen steadily in these two flyways with wintering populations approaching 2 million birds in the mid-1980's. Wintering populations of Pacific flyway geese have demonstrated variation in the recent past. However, significant declines have occurred with certain subspecies. The Pacific flyway contains the only threatened and endangered goose in the continental United States, the Aleutian Canada goose with a 1984–85 wintering population of about 3,800 birds. In

addition, decreasing numbers of the dusky and cackling Canada geese and white-fronted geese occur in the Pacific flyway (Raveling 1984).

As was the case for ducks, a primary influence on goose numbers is the amount and quality of wetland habitats. However, geese have prospered from some practices that have been detrimental to ducks, especially the expansion of cropland acreage (USDI Fish and Wildlife Service 1987a). The introduction of Canada geese into nesting habitats previously not used or underutilized by geese has also contributed to the observed population increases in this species.

Swans.—Recent wintering population levels of swans have varied from 72,000 to 148,000 birds. Eastern and western subpopulations of the tundra swan have demonstrated a slow but consistent upward trend. The trumpeter swan population is one of North America's brightest waterfowl successes. From a population of approximately 66 birds known in 1933, the species now numbers approximately 10,000 birds. Trumpeter swans are divided into three subpopulations, none of which are now considered to be in danger of extinction (USDI Fish and Wildlife Service, and Canadian Wildlife Service 1986a).

Woodcock.—The American woodcock is censused annually by volunteers throughout its breeding range. Annual indices (number of singing males per route) of the breeding population have been relatively stable throughout the composite range of the species during the last 20 years (fig. 12). The woodcock breeding index was lower during the 1982–1984 period than at any other time since the survey began. However, the indices have since recovered and are approaching the long-term mean.

When annual totals of the breeding populations are examined together, important differences among subregions are masked. Present evidence suggests two distinct breeding subpopulations of woodcock (Owen 1977). The Eastern region is comprised primarily of Atlantic coastal states, the Central region includes those states from the north-central lake region south to Louisiana, Mississippi, and Alabama. The Central region has consistently reflected higher numbers of singing males per route than has the Eastern region and has experienced a general increase of nearly one singing male per route from 1968 to 1987. Despite the observed increases, recruitment as measured by the number of young per adult female in the central region has declined significantly (Kelly 1986)—a trend that has raised concern for the long-term maintenance of population levels.

In contrast to the Central region, the Eastern region has shown a gradual decline of nearly one singing male per route during the last 20 years. Although the cause for the decline has not been identified, evidence suggests that land-use changes and forest succession probably have resulted in deterioration of preferred breeding habitat (Coulter and Baird 1982, Dwyer et al. 1983). Woodcocks prefer early successional stages of second-growth hardwood forest associated with fields and forest openings on mesic sites (USDI Fish and Wildlife Service 1987a).

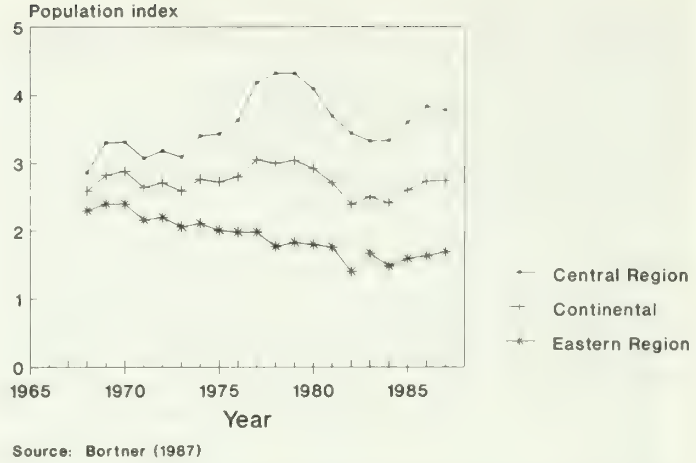


Figure 12.—Woodcock breeding population indices (singing males per route) by management region.

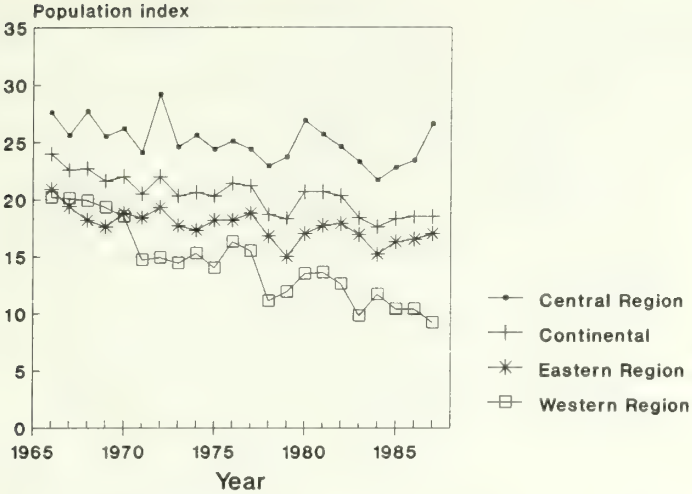
Mourning dove.—With populations estimated at about 500 million, the mourning dove is one of the most abundant birds in North America (Dolton 1986, USDI Fish and Wildlife Service 1987a). The Fish and Wildlife Service surveys breeding dove populations throughout three management regions of the nation with the assistance of volunteers. These regions are the Eastern, bounded on the west by the Mississippi River except it includes Louisiana; the Central composed of the states between the Mississippi River and the western edge of states between New Mexico and Montana; and the Western, which includes the remaining seven western states.

Nationally, breeding populations of mourning doves have gradually declined over the period of 1966–87 (Dolton 1987). Indices of breeding dove populations reached a low in 1984 at a level approximately 75% of the breeding populations in 1966 (fig. 13). Regionally, call-count indices of mourning dove populations have been declining in the East and West during the same period. The decline has been greatest in the Western region, where the average number of doves heard per route declined from 20.2 in 1966 to 9.2 in 1987 (Dolton 1987).

Although doves are tolerant of human activity (USDI Fish and Wildlife Service 1987a), changes associated with agricultural practices, including the loss of shelterbelts, may be having negative impacts on breeding populations (Dunks et al. 1982, Tomlinson et al. 1987).

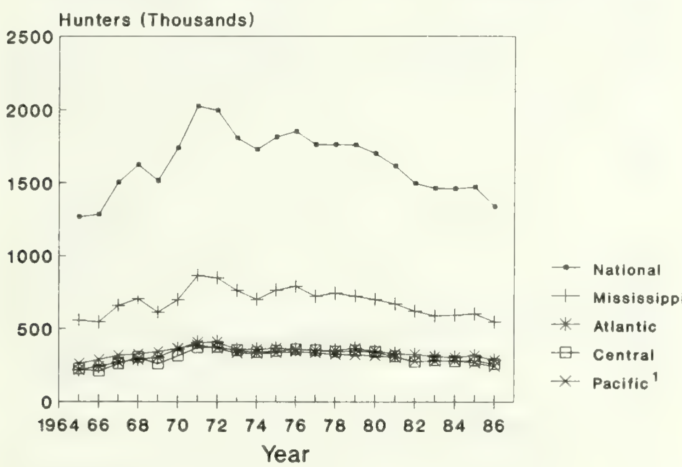
Migratory game bird hunters.—Hunting activity associated with migratory game birds is influenced by hunting regulations that combine ducks and geese on one licence, and the webless migratory game birds (doves, woodcock, snipe, and other shorebirds) on another.

Duck and goose hunters.—The number of active waterfowl hunters in the nation climbed from 1.2 million in 1965, to a high of over 2 million in 1971, and has since declined steadily to 1.3 million by 1986 (fig. 14). Waterfowl hunters in each flyway have been consistent with the national trend. The Mississippi flyway has had about 2.5 times more hunters as occur in any other flyway.



Source: Dolton (1987)

Figure 13.—Mourning dove breeding population indices (average number of birds heard per route) by management unit.



[1]Includes Alaska

Source: Data on file with the USDI, Fish and Wildlife Service, Office of Migratory Bird Management

Figure 14.—Number of waterfowl hunters by administrative flyway.

After reaching a peak of nearly 850,000 hunters by 1971, the number dropped to around 550,000 hunters in 1986 for an average annual flyway loss of 20,000 hunters. The Atlantic, Central, and Pacific flyways reflect similar hunter trends. These flyways climbed from 200,000 to 300,000 hunters in 1965, to nearly 400,000 by 1971, and then declined to levels characteristic of the mid-1960's. The average annual rate of decline since the 1970's is consistent across all flyways at about 2.4%.

The decline in waterfowl hunters represents a continuation of a long-term trend (Trost et al. 1987); however, the specific factors responsible for the decline have not been identified. The decline does not appear to be the result of stabilized season lengths and bag limits during the period 1980 to 1985 (Trost et al. 1987). One explanation for fewer waterfowl hunters may be the accessibility of land. A recent survey by the National Shooting Sports Foundation (1986) reported that land accessibility and crowded hunting conditions constrained waterfowl hunting opportunities more frequently than any other type of hunting. This may result from wetland acreage loss, closure of acres to hunting, or increased access restrictions to the general public from hunter lease agreements.

The decline in active waterfowl hunters is also reflected in the number of migratory bird hunting and conservation stamps sold. These stamps are required of hunters but they are also purchased by collectors and more recently by nonhunting conservationists. From a total of 1.6 million stamps sold in 1965, to a high of 2.4 million in 1971, the number of duck stamps sold dropped to approximately 1.9 million in 1985. The number of stamps sold has declined less rapidly than the number of hunters since 1971 indicating increasing interest in waterfowl conservation by the non-hunting public. Conservationist interest stems, in part, from the fact that a portion of the money goes towards wetland habitat acquisition and management.

Woodcock hunters.—Because there is no national survey of woodcock hunters (USDI Fish and Wildlife Service 1987a), information on woodcock hunter participation is much less complete than for waterfowl. A recently completed environmental assessment of woodcock harvests (USDI Fish and Wildlife Service 1985) estimated the number of woodcock hunters for the 34 states that regulated seasons to be approximately 700,000 (split evenly between the two woodcock management regions). The number of woodcock hunters was believed to be increasing from the 1960's through the early 1970's, but participation has declined since that time (USDI Fish and Wildlife Service 1985).

More detailed trends of woodcock hunters was available for the South. However, since woodcock hunting effort is often incidental to the hunting of other game, interpretation of trends is difficult (Wood et al. 1985). The Southeastern Association of Fish and Wildlife Agencies periodically surveys the number of woodcock hunters. For the period 1980–1986, the total declined by 32% in the seven states from Maryland to Florida (table 14). In the southern part of the Central woodcock management region, the trend has been considerably different. A 15% increase in hunters was estimated between 1980 and 1982, after which the number of hunters dropped by 29% in the next 4 years.

Mourning dove hunters.—Although information on the nationwide number of dove hunters is not available, some information exists for portions of specific management regions. Hunter trends since the mid-1960s in the western management region were addressed by Tomlinson et al. (1987). The average number of dove hunters declined from 418,000 to 376,000 between the periods of 1966–1968 and 1981–1983. This trend could be expected given the previously noted decline in dove populations over the same period.

Trends for the most recent decade in the Eastern and Central mourning dove management regions have been estimated by the Southeastern Association of Fish and Wildlife Agencies. The majority of these states are in

Table 14.—Estimated number of woodcock and mourning dove hunters in the southern United States by management region.

	Woodcock		Mourning Dove	
Year	Eastern management region (7 states)	Central management region (7 states)	Eastern management region (12 states)	Central management region (4 states)
1980	32,272	69,691	1,024,589	463,907
1981	31,641	79,169	1,092,152	457,706
1982	28,063	80,052	1,108,142	616,572
1984	25,977	77,176	1,077,213	620,471
1986	22,071	57,502	1,082,588	594,303

Source: Southeastern Association of Fish and Wildlife Agencies (1980–1982, 1984, 1986).

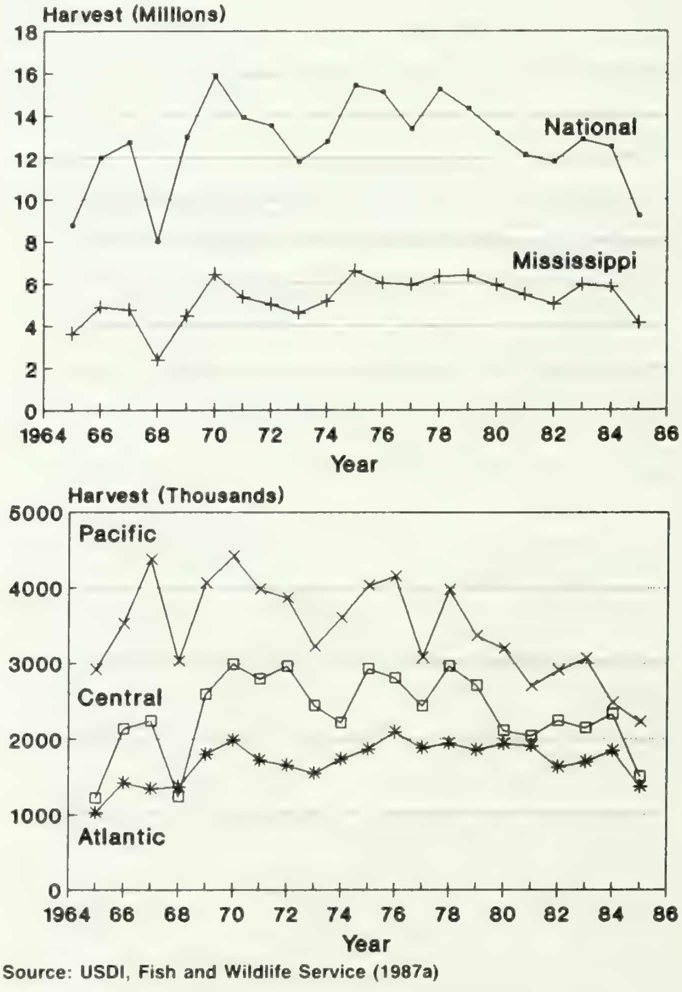
the Eastern region with the Central region being represented by four states. The trend in number of hunters pursuing mourning dove for the period 1980–1986 was stable in the East (table 14). The trend for four states in the southeastern part of the Central region increased during the period 1981–1984, then declined slightly by 1986. The estimated number of dove hunters in the Central region is heavily weighted by the large number of dove hunters from Texas where they are three to five times more numerous than in any other state in the region.

Migratory game bird harvest.—Because of their migratory habits, waterfowl and the webless migratory birds have a harvest regulation history of national and international interest. Laws and international treaties have been rigorously enforced and have made the harvest of migratory game birds a positive management tool in recent history. A recent cooperative study between the United States and Canada to examine the effects of harvest on waterfowl populations (Brace et al. 1987) offers evidence for the continuing desire to base harvest regulations on scientifically sound principles.

Duck harvest.—The 20-year trend of total duck harvest is one of general increase with harvests going from an average of 10.9 million ducks during the 1965–1969 period, to an average of 11.8 million ducks during the 1981–1985 period (fig. 15). The short-term pattern, however, is downward—harvests have declined by 28% since 1980.

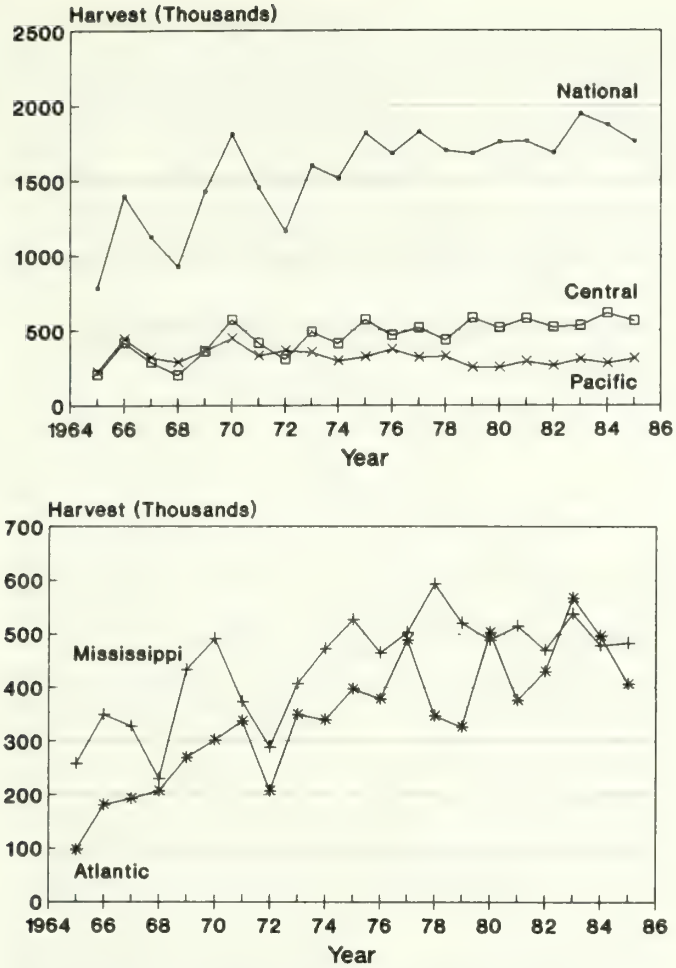
Duck harvests by flyway show little deviation from the noted national trends. Since the early 1970's, the Atlantic and Mississippi flyways have shown generally stable duck harvests, Central flyway harvests have fluctuated, and the Pacific flyway has shown a downward harvest trend. The Atlantic flyway has consistently harvested the smallest number of ducks of the four flyways with 1 million ducks harvested in 1965, increasing to around 2 million by 1970 and remaining there. The Mississippi flyway has consistently harvested the largest number of ducks, fluctuating between 5 and 6 million since 1980. The Mississippi flyway, as with the Central and Pacific flyways, realized a sharp decline in 1969. Reduced production caused by drought on the breeding grounds may have been responsible for the low 1969 harvest. The Central flyway harvests have remained between 2 and 3 million ducks since 1970. Harvest in the Pacific flyway, after peaking near 4.5 million ducks in 1971, has declined by 40%.

Several factors affect the annual duck harvest including population levels, numbers of hunters, weather, and regulations. The relatively stable harvests since the early 1970's noted in the Atlantic and Mississippi flyways is particularly surprising given the significant declines in the number of active hunters and the breeding duck



Source: USDI, Fish and Wildlife Service (1987a)

Figure 15.—National and flyway duck harvest trends.



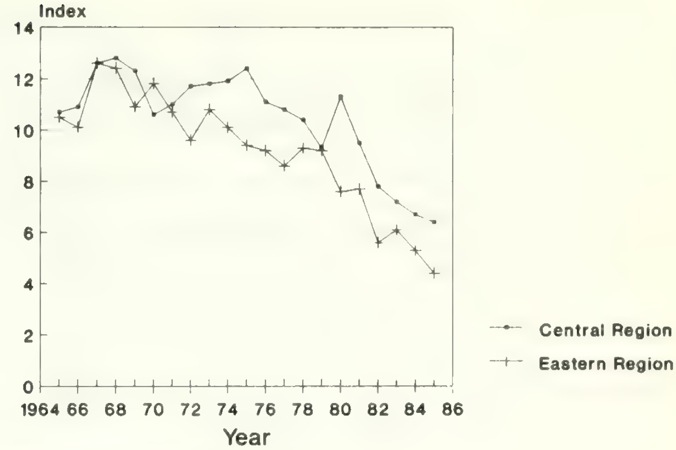
Source: Data on file with the USDI, Fish and Wildlife Service, Office of Migratory Bird Management

Figure 16.—National and flyway goose harvest trends.

populations. Thus, it appears that success rates have been increasing since the early 1970's (USDI Fish and Wildlife Service 1987a).

To learn more about the factors that affect harvest rates, the United States and Canada undertook a 5-year (1980–1985) cooperative study to evaluate stabilized season lengths and bag limits. The preliminary findings of this study indicated that harvests are a direct function of hunter numbers together with hunter success and population abundance (Trost et al. 1987). Weather and population age structure were not clearly established as affecting harvest levels. The relationship between the number of hunters and the number of waterfowl harvested was also found to be nonlinear such that the harvest rate of small populations was higher than the harvest rate of large populations. Finding the harvest rate threshold for each species requires further research.

Goose harvest.—The number of geese taken by hunters has increased since 1965 (fig. 16). Harvests have gone from a low of 750,000 in 1966 to nearly 1.9 million in 1985. Harvests during the last 10 years have been consistently at or above 1.5 million. The Canada goose



Source: Kelly (1986)

Figure 17.—Trends in woodcock seasonal hunting success by management region.

is the most abundant species harvested, accounting for 60% of the harvest (USDI Fish and Wildlife Service 1987a). The influence of growing national goose populations explains, in part, the significant gain in harvests over the last 20 years.

The harvest trend for geese has been upward in three of the four flyways. The Atlantic flyway goose harvest has been increasing since 1965. Slightly more than 150,000 geese were harvested in 1965 and that number grew to nearly 500,000 by the mid-1980's. The Mississippi and Central flyway goose harvests have each increased from about a quarter million birds in 1965 to around a half million in 1971, where harvests have remained at fairly stable levels. The Pacific flyway has shown gradual declines in the goose harvest since the mid-1970's. After peaking at 450,000 birds in the early 1970's, the Pacific goose harvest has stabilized near 300,000 birds.

Woodcock harvest.—American woodcock harvests are monitored annually by the states and the Fish and Wildlife Service through bag checks and voluntary submissions of bird wings by woodcock hunters. Recent harvest calculations by the Fish and Wildlife Service (1987a) estimate that 827,000 birds were taken by hunters in the Eastern management region, while approximately 1.2 million birds were harvested in the Central region. Trends in woodcock harvests are not estimated directly, but are monitored through an index of success (birds per season per hunter). During the period of 1965–1975, the index ranged between 10 and 13. Since the mid 1970's, however, success has declined significantly (Kelly 1986). Both the Eastern and Central management units have experienced approximately a 50% decline in the average number of birds bagged per season (fig. 17).

A second source of woodcock harvest information comes from the Southeastern Association of Fish and Wildlife Agencies annual Vital Statistics reports. The trends are generally consistent with those described by Kelly (1986). In the southern portion of the Eastern management region, as represented by the seven states

from Maryland to Florida, woodcock harvests steadily dropped by 43% during the period 1980–1986. In six southern states in the Central management region, woodcock harvests increased from 1980 to 1982 and then dropped a dramatic 70% by 1986.

Mourning dove harvest.—No national survey monitors mourning dove harvests. Data derived from state agencies yield a national harvest estimate of up to 51 million birds (USDI Fish and Wildlife Service 1987a). This estimate far exceeds the harvest of any other game species. Consistent with the population and hunter participation declines noted in the Western region, Tomlinson et al. (1987) estimated that harvests have declined from an average of 7.3 million in 1966–1968 to 5.7 million in 1981–1983. Trends in the Eastern and Central management regions have remained relatively stable in recent years. The Southeastern Association of Fish and Wildlife Agencies has estimated the number of doves harvested in the cooperating states and found that in the southern portion of the Eastern management region harvests fluctuated between 24 and 25 million during 1980–1986. Harvest statistics from three states in the Central management region showed an increase from 7.7 to 10.1 million birds during the 1980–1984 period, followed by a slight drop in 1986.

Big Game

Big game is a general term that includes large mammals taken for sport or subsistence. Some states regard the wild turkey as big game, too. Besides being an important outdoor recreational activity, big game hunting is also important to many rural economies which benefit from food, lodging, and other travel-related expenditures. In 1985, big game hunters accounted for 60% of all hunting-related expenditures (USDI Fish and Wildlife Service 1986b).

People do not generally appreciate that many big game populations are now more secure, more widely distributed, and more abundant than they were at the turn of the century (Wildlife Management Institute Staff 1978). It is important to recognize, however, that despite significant gains in some selected populations, the diversity of big game within certain regions of the country has changed dramatically over time. Where deer now dominate in the East, elk, bison, moose, wolves, and mountain lions were once members of the regional fauna (Matthiessen 1987).

Enactment of protective legislation and professional management have undoubtedly contributed to the recovery of many big game species. For example, the most widely hunted big game species, white-tailed deer (USDA Forest Service 1981), has a population 47 times larger now than at the turn of the century (Downing 1987). However, past successes may not reflect future resource status. Increased expenditures for management will be required to maintain the quantity and quality of big game habitats and populations (Bailey 1980, Flather et al. 1989, Halls 1984, Miller and Holbrook 1983).

Populations.—As is the case with many wildlife species, no standardized inventory assesses national or regional trends in big game populations. Even the "Big Game Inventory" formally conducted by the Fish and Wildlife Service was simply a compilation from state wildlife agencies. The information reported here also represents a compilation of data that was obtained largely from cooperating state wildlife agencies. The species discussed as representative of big game population status vary by assessment regions (see fig. 1) due to regional differences in animal distributions and management emphasis.

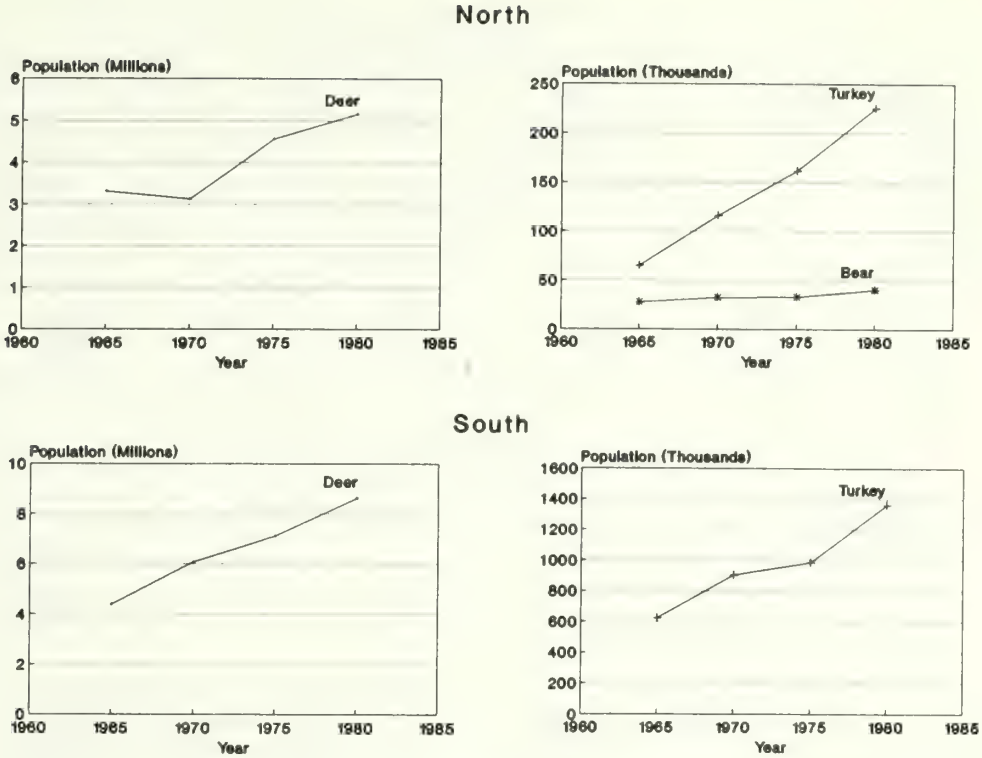
North.—The big game species in the Northern region include white-tailed deer, black bear, and wild turkey. White-tailed deer is by far the most abundant. Of the 20 states comprising the region, 19 reported trend information since 1965. Eighty percent of the states reported increased deer populations since 1965; the remaining 20% split evenly between stable or downward trends.

A more quantitative evaluation of deer trends was possible with the majority of the states. Eighteen states provided deer population estimates from 1965 through 1980, and 11 states provided a complete time trace through 1985. In both cases, significant increases in white-tailed deer populations have been observed. From 1965 to 1980, deer populations increased by approximately 120,000 animals (4%) per year (fig. 18). The reasons for these gains can be attributed to the adaptability of the species and more favorable habitat associated with land-use and land management shifts (Downing 1987).

Black bear trends have been more variable. Of the 11 states reporting trends since the mid-1960's, five showed increases, one state reported a decline, and the remainder had relatively stable populations. Of the states with relatively stable populations, two have shown declining trends since the mid-1970's. However, states that have witnessed both long and short-term declines contribute less to the total regional population than states with increasing trends. Consequently, the net increase in black bear populations in nine states reporting quantitative trends has averaged 850 bears (3%) per year (fig. 18). Though black bears have remained relatively abundant, they are now restricted primarily to the more remote and inaccessible portions of their former range (Raybourne 1987) and are relatively less tolerant of human activities in their habitat than are deer or wild turkey.

The wild turkey has experienced the greatest gains of the three big game species in the North. Of the 18 states that have provided population trends, all have estimated population increases over the period from 1965 to 1985. Turkey populations across these reporting states have increased by nearly 250% from 1965 to 1980—an average increase of nearly 8% annually (fig. 18). Restocking programs along with favorable landscape changes have contributed to the significant increases in turkeys.

South.—The two most important big game species in the South are the white-tailed deer and wild turkey (USDA Forest Service 1981). These species have been monitored and managed more intensively than most species in the region because of their importance to hunting. As of 1980, a compilation of state agency statistics showed that the South supported 8.6 million deer and



Source: Data supplied by state fish and wildlife agencies

Figure 18.—Recent trends in big game populations in the Northern and Southern regions.

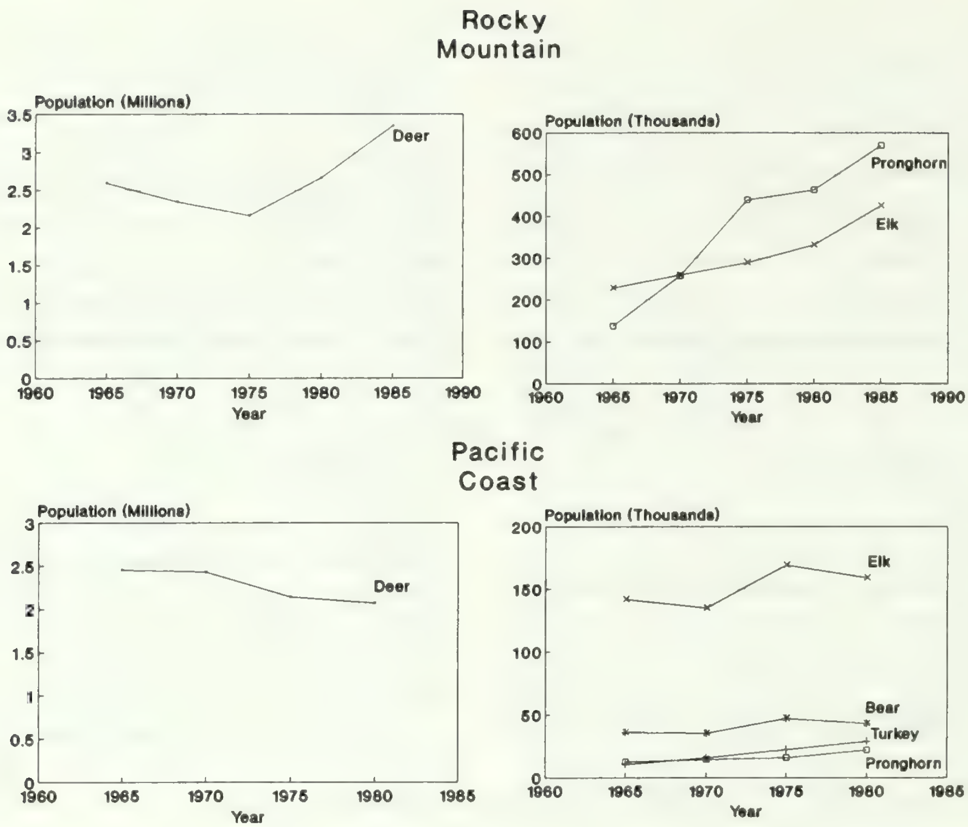
1.4 million turkeys, levels 29 and 47 times the national population estimates for these species in the early 1900's, respectively. The recovery of these populations since the turn of the century has continued over the last 20 years. Deer populations have increased 96% (70,000 animals/ year), while turkeys have increased by 120% (50,000 birds/year) (fig. 18). The population increases of both deer and turkey appear to be consistent in the majority of southern states. Twelve out of the 13 southern states reported significant increases in deer and 10 states reported gains in turkeys.

Rocky Mountain.—The West has a greater diversity of big game animals than the East. Information provided by the states was sufficient to discuss trends for deer (mule and white-tailed combined), elk, and pronghorn. Population trends for bighorn sheep, mountain goat, and moose were available from federal land managing agencies and therefore are discussed in the Wildlife and Fish Resources on Public Lands section of this chapter. Because big game habitats in the West are predominantly found on public land, most big game species are more numerous on and more heavily hunted on public lands (Hoekstra et al. 1981).

Mule deer are by far the most abundant big game species in the Rocky Mountain region. Because mule and white-tailed deer are not always distinguished in state statistics, the two species are combined here. The decline in deer populations during the early 1970's (fig. 19) was due to the documented decline in mule deer that apparently occurred throughout the West. Wallmo (1978) speculated that loss of habitat associated with human development was partially responsible for the decline. However, this does not explain why the number of mule deer have since recovered. An alternative explanation for the decline is that deer herds could not support the liberal hunting regulations that were in place during the 1970's—with more restrictive harvest regulations populations increased (Wagner, pers. comm., 1988). In 1985, 11 of the 12 Rocky Mountain states reported populations of more than 3 million animals.

Elk were once the most widely distributed cervid in North America (Boyd 1978). Restriction of elk range resulted from both exploitation and land-use conversions associated with human settlement (Thomas and Bryant 1987). Their current distribution is now essentially confined to the West. Populations over the current range have been recovering due to harvest regulation and intensive transplanting programs. Populations in 11 out of the 12 western states have increased approximately 85% for an average annual increase of 10,000 animals since 1965 (fig. 19).

Pronghorn populations also have experienced significant increases in the last 20 years. Once numbering 30–40 million, populations in the 1920's had been reduced to 13,000 animals (Yoakum 1978). Pronghorn populations have increased dramatically since that time. Eleven states in the Rocky Mountain region estimated the 1985 pronghorn population to be between 550,000 to 600,000



Source: Data supplied from state fish and wildlife agencies

Figure 19.—Recent trends in big game populations in the Rocky Mountain and Pacific Coast regions.

animals. Trends over the last 20 years show consistent increases with an average annual gain of approximately 22,000 animals (fig. 19). Regulation of hunting has been an important factor in the recovery of the species; however, improvement in range conditions and reversion of land to more suitable pronghorn habitat have also encouraged recovery (Wagner 1985, Yoakum 1978).

Pacific Coast.—The trends of big game populations in the Pacific Coast region are similar to those in the Rocky Mountains. Deer (mule, black-tailed, and white-tailed) are the most abundant big game species comprising nearly 90% of the total big game population in the region. Deer populations declined from 1965 through 1980 for an overall loss of about 15% (fig. 19). Declines were most rapid from 1970 through 1975, after which populations appeared to stabilize. Commonly cited reasons for the decline include severe weather and deterioration of winter and summer habitat due to fire suppression, grazing, road development, and human harassment (Connolly 1981).

Elk population trends have fluctuated recently. The general trend, however has been upward since the 1960's (fig. 19). The reasons for the increase are more intensive management through harvest regulations and transplanting programs and the availability of habitat to support expanding numbers (Thomas and Bryant 1987).

Black bear, pronghorn, and wild turkey comprise a much smaller proportion of big game in the Pacific Coast region (fig. 19). Bear population estimates are incomplete and the trends depicted only represent information from two states. Bear populations appear to have increased from the 1960's through the early 1970's. Pronghorn and wild turkey populations grew consistently, nearly doubling and tripling their numbers from 1965 to 1980, respectively.

Big game hunters.—The number of big game hunters is influenced by harvest regulations and socioeconomic factors affecting recreational preferences. The number of big game hunters increased from about 6.6 million in 1965 to 12.6 million in 1985 (table 15)—a proportional increase from 4.6% to 6.4% of the U.S. population 12 years old or older. The percent of the population participating in big game hunting increased a constant 0.4% through 1975. After declining slightly in 1980, proportional participation increased to mid-1970 levels in 1985. Potential causes for the declining national rate of participation include decreasing land accessibility, crowded hunting areas, and less leisure time to participate (National Shooting Sports Foundation 1986).

Regionally, the number of big game hunters has increased in the North, South, and Rocky Mountains

Table 15.—National and regional participation trends in big game hunting.[1]

Region	1965	1970	1975	1980	1985
			Thousands		
Total	6,566	7,774	11,037	11,047	12,576
(% population)	(4.6)	(5.0)	(6.4)	(6.0)	(6.4)
North				5,832 (7)	6,121 (7)
South				4,173 (8)	4,599 (8)
Rocky Mountain				1,412 (11)	1,694 (13)
Pacific Coast				969 (4)	935 (4)

[1]*Regional totals do not sum to national total since hunters may hunt in more than one state.*
NOTE: Total participants based on people 12 years old and older. Regional participants in 1980 and 1985 are based on persons 16 years and older. For the purposes of trend analysis, the national figures reported here for 19651985 have been adjusted to permit comparison across years, as explained in appendix C of USDI Fish and Wildlife Service (1988b).
Source: USDI Fish and Wildlife Service (1988b); USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

(table 15). The number of big game hunters actually declined in the Pacific Coast region.

Deer are by far the most commonly hunted big game species—over 95% of all big game hunters sought deer in 1980 (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982). Wild turkey was the second most commonly sought species, with 12% of big game hunters pursuing this bird. The number of elk, bear, pronghorn, or moose hunters was relatively small, constituting about 12.5% of all big game hunters. The abundance of deer and their distribution near high population centers in the East explains the large numbers of deer hunters. Examining trends in species hunted from 1981–1985, the National Shooting Sports Foundation (1986) found that deer and turkey were the only big game species that were hunted more frequently over that 5-year period.

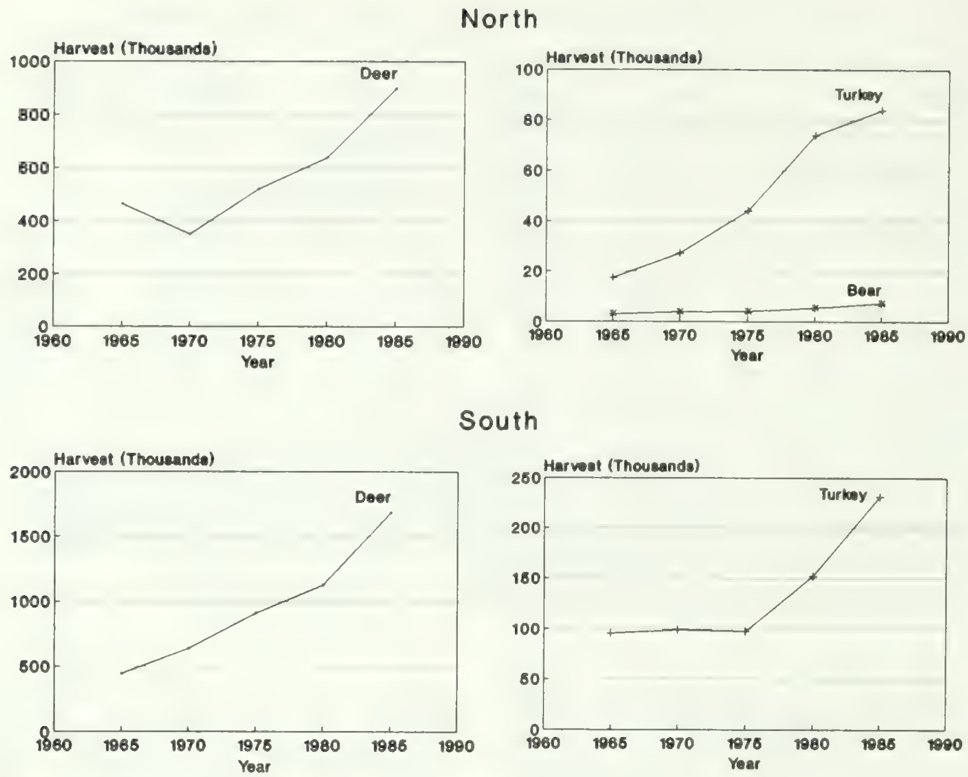
Big game harvest.—One of the major tools available to states for managing big game species is harvest regulation. This is particularly true where natural predators of big game are no longer present and some form of removal helps balance animal numbers with habitat resources. Much of the research recently developed to aid big game management has focused on quantifying the effects of exploitation on large mammal populations (see Caughley 1977, Fowler and Smith 1981, Starfield and Bleloch 1986). Because of this focus and the relative ease of estimation, big game harvest statistics have tended to be more geographically and temporally complete. The most basic factors influencing big game harvests are population levels and hunter effort. However, factors such as weather, special regulations, and accessibility will modify the expected hunter success rates. Generally, the harvest levels reported here follow the expectation based on animal populations and hunter effort.

North.—Of the 20 states comprising the North, 15, 7, and 10 states provided harvest trends from 1965 through 1985 for deer, bear, and turkey, respectively. All harvest levels have increased over the last 20 years (fig. 20), as expected given the notable population increases of these species. Wild turkey showed the greatest increase in harvest levels—380% over the last 20 years for an average increase of 3,300 birds annually. Bear harvests, in the seven reporting states, increased 140% or 210 animals per year. Although deer showed the smallest proportional increase (94%), the observed annual increase of nearly 22,000 animals harvested over the last 20 years emphasizes the dominating importance of this species to big game hunters in the North.

South.—The dramatic increases in deer and turkey populations in the South is tracked closely by harvest trends (fig. 20). Deer harvests increased nearly 280% while turkey harvests increased 143% from 1965 to 1985. These relative increases translate into average annual gains of 62,000 and 6,800 animals bagged, respectively. The increase in deer harvests were relatively steady over the period, in contrast to turkey harvests which showed more rapid gains in the last 10-year period (1975–1985). This may indicate that turkey populations reached sufficient levels in the mid-1970's to trigger an influx of new users.

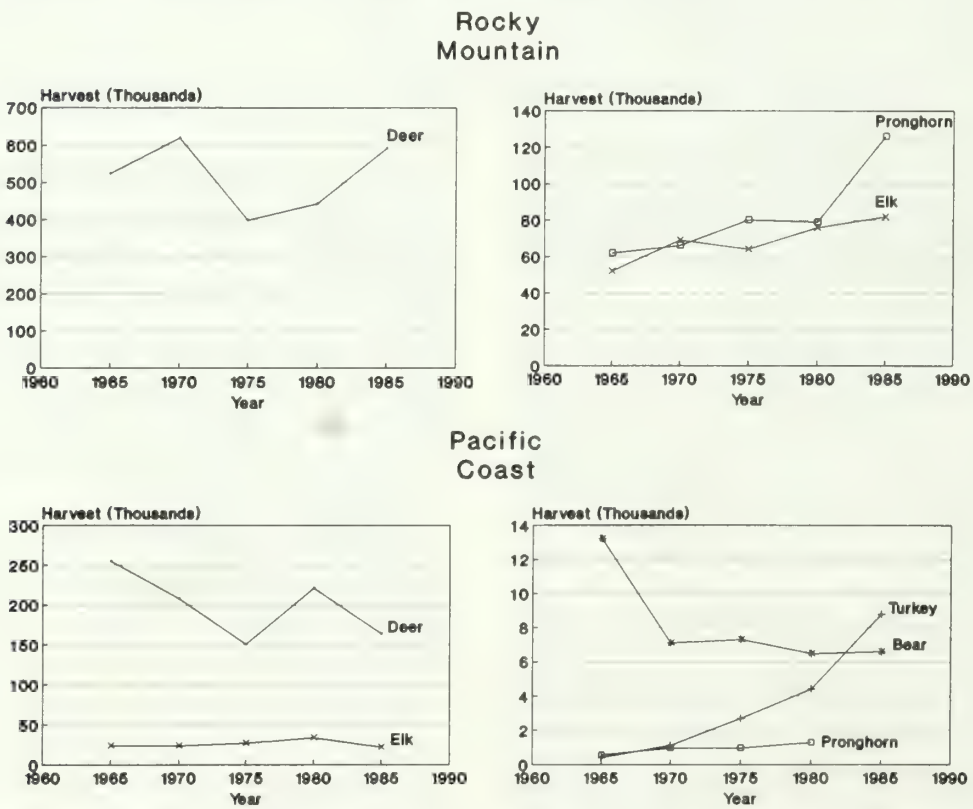
Rocky Mountain.—Big game harvest trend data were available from all states in the Rocky Mountain region. Elk and pronghorn harvests have increased by 58% and 104%, respectively, over the last two decades (fig. 21). Elk harvest increases appear to be consistent across reporting states. Conversely, pronghorn harvest trends varied by state with eight states reporting increases, two reporting declines, and two reporting relatively stable harvests. States not reporting increases are characterized by low pronghorn populations and contribute little to the overall regional harvest trend.

Deer (mule and white-tailed) harvests have qualitatively mimicked the noted population trends. Although deer populations declined consistently from 1965



Source: Data supplied by state fish and wildlife agencies

Figure 20.—Recent trends in big game harvests in the Northern and Southern regions.



Source: Data supplied from state fish and wildlife agencies

Figure 21.—Recent trends in big game harvests in the Rocky Mountain and Pacific Coast regions.

through the mid-1970's, harvests actually increased between 1965 and 1970, before declining by 36% in 1975. By 1985, deer harvests increased to near 1970 levels. State trends tended to be consistent with the regional trend. Exceptions occurred in states along the eastern border of the region where whitetails are the predominant deer species. In these states, consistent increases in harvests have been observed.

Pacific Coast.—Changes in deer harvest over the last 20 years have been heavily influenced by the mule deer decline that evidently occurred throughout the West. Deer harvests declined by over 40% from 1965 to 1975, increased to pre-crash levels in 1980, only to decline again in 1985 (fig. 21).

Elk and pronghorn harvest trends have consistently increased from 1965 through 1980 (fig. 21). Pronghorn harvests more than doubled between 1965 and 1980. As with deer, elk harvests have declined since 1980. The magnitude of the decline (35%) was influenced heavily by a record high harvest in 1980 in one of the reporting states.

After dropping nearly 50% between 1965 and 1970, bear harvests have fluctuated since 1970 (fig. 21). Not all reporting states were consistent in this pattern; harvests have doubled since 1970 in one state and declines have been reported in two others.

Turkey harvests have experienced the greatest relative increase of all big game species in the Pacific Coast region. From a low of about 400 birds in 1965, harvests have increased to nearly 9,000 in 1985 (fig. 21).

Small Game

Animals considered small game generally include resident game birds and mammals but exclude migratory birds and furbearers. The word "upland" frequently modifies the designation small game to indicate these animals associate with forest, range, or agricultural habitats rather than wetland or aquatic systems. States vary in the species managed as small game. For the purposes of this report, population and harvest trends of grouse, squirrel, rabbit, quail, and pheasant are reviewed as repesentative examples of the nation's small game resource.

Populations.—Most states do not monitor small game populations, but rather use harvest data to evaluate resource status. Consequently, few states contributed small game information; therefore, trends must be interpreted with caution. Harvest statistics provided a more regionally representative sample of states from which trends in small game resources could be evaluated.

Populations of small game are relatively more responsive to environmental factors such as weather and vegetation than big game. Vegetation, as a habitat component, is probably the major factor that can be influenced to change small game populations. Harvest of small game populations generally does not withdraw sufficient numbers of the population stock to effectively change the population because most small game species have a high reproductive potential.

Some national trends in small game populations are apparent from an overview of regional summaries. Small game populations associated with agricultural land uses are declining. Pheasant, quail, prairie grouse, and eastern cottontail populations all have shown a downward trend over the 1965 to 1985 period. Small game species associated with forested habitats, including squirrel and grouse, remained stable or increased slightly over the same 20-year period. A more detailed account of recent population trends by assessment region follows.

North.—Northern small game population trends are, in general, consistent with national pattern by species and habitat (fig. 22). Northern bobwhite reach the northern extent of their range in this region. Consequently, weather is an important factor influencing quail numbers. The trend in northern bobwhite numbers has been slightly downward (10%) since 1965 with the greatest decline occurring in the last 10 years. Rabbit and hare populations have gradually declined by 20% since 1965 while pheasant numbers have declined by over 60% in one mid-Atlantic state. The declines in quail, rabbit, and pheasant populations are considered to be habitat related. These species have dwindled with reduced interspersion of early forest succession and agriculture, with bigger farms but fewer fencerows and field borders, and with more intensive farming including more herbicide use and fall plowing (National Academy of Sciences, National Research Council 1982).

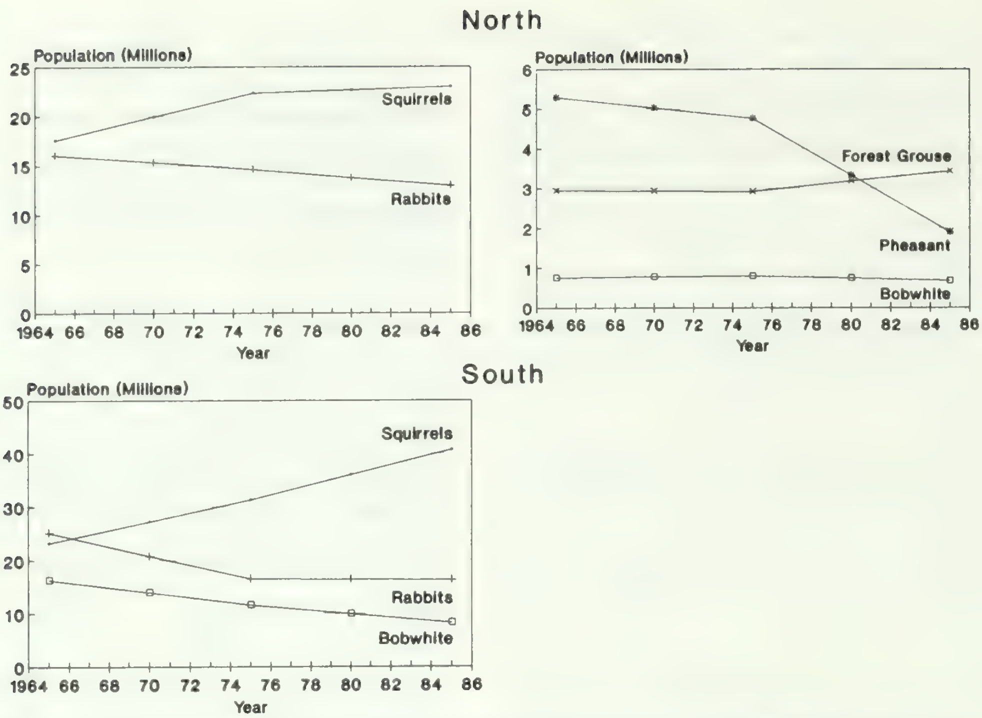
In contrast to the small game species associated with agricultural and shrubland habitats, squirrel populations have increased by over 30% in the forested Northeast, yet have declined slightly in the more agricultural Midwest. These trends follow the changes in land-use patterns—small farm woodlots are being removed in the Midwest while maturing forests in the Northeast are providing more suitable squirrel habitat.

South.—The South's populations of northern bobwhite and eastern cottontail have recently declined by 50% and 35%, respectively (fig. 22). States along the northern boundary have had relatively stable quail populations; the decline has occurred mostly in the deep South. In addition to more intensive agricultural practices and the decline of early succession vegetation, state regulations restricting the use of prescribed burning have resulted in less favorable habitat conditions (Landers 1987) for many small game species such as northern bobwhite.

As in the North, trends for forest small game have been more favorable than for species associated with agricultural habitats. Squirrel populations in four states have been increasing steadily over the last 20 years, for an overall increase exceeding 75%.

Rocky Mountain.—Pheasant populations in the Great Plains have declined in the traditionally high-population central states and remained relatively stable in the more northeastern states. In three states that have reported population trends from 1965 to 1985, pheasant numbers have dropped by over 50% (fig. 23).

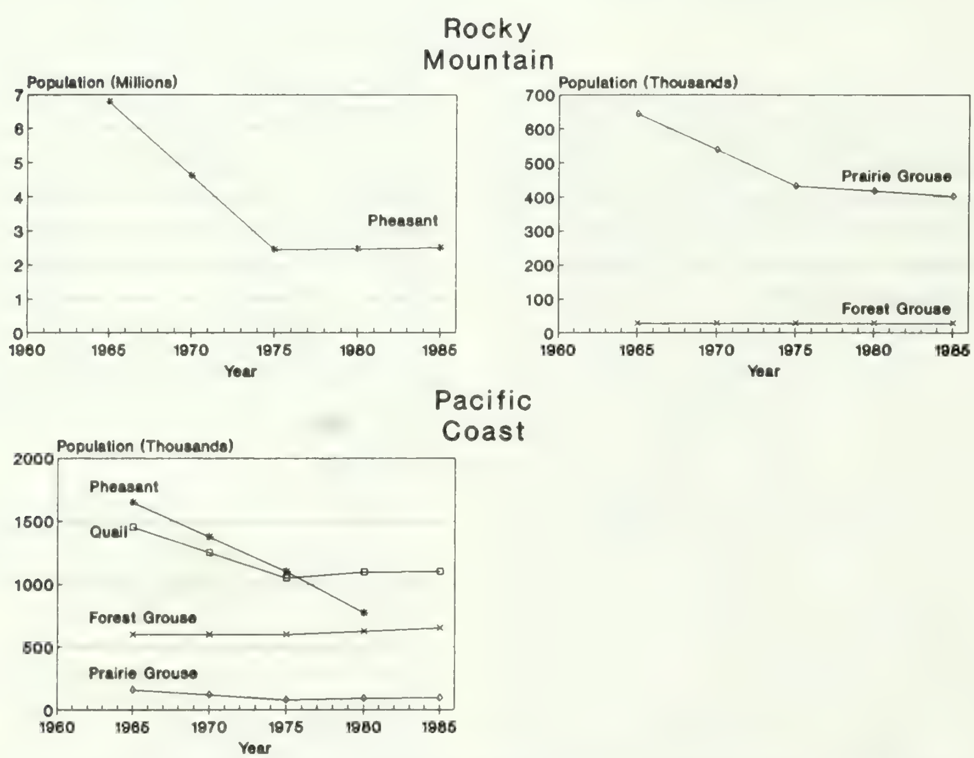
Grouse populations have varied by species. Composite population trends for prairie grouse species have shown consistent declines over the recent historical period, while forest grouse species have shown relatively



NOTE.—Number of Northern states reporting population trends through 1985: Pheasants-1, Quail-2, Rabbits-2, Squirrels-2.Forest Grouse-3. Number of Southern states reporting population trends through 1985: Quail-3, Rabbits-4, Squirrels-4

Source: Data supplied by state fish and wildlife agencies

Figure 22.—Recent trends in small game populations in the Northern and Southern regions.



NOTE.—Number of Rocky Mountain states reporting population trends through 1985: Pheasants-3, Prairie Grouse-3, Forest Grouse-1. Number of PAcific Coast states reporting population trends: Pheasants-1, Quail-1, Prairie Grouse-1, Forest Grouse-1

Source: Data supplied by state fish and wildlife agencies

Figure 23.—Recent trends in small game populations in the Rocky Mountain and Pacific Coast regions.

stable numbers. Populations of sharp-tailed grouse (Miller and Graul 1980) and sage grouse (Autenrieth 1986) in the Rocky Mountain region have declined due to agricultural practices which have reduced critical cover and food plants.

Pacific Coast.—Small game population estimates were available from one state. As observed in the other regions, trends have been mixed. Forest and prairie grouse populations show divergent trends. Forest grouse species have increased slightly since 1975 while sage grouse have declined by 40% since 1965. Quail populations (bobwhite and western species) dropped by 25% and pheasants have declined by more than 50% (fig. 23).

Small game hunters.—The number of small game hunters has historically represented approximately 8% of the U.S. population 12 years old and older (table 16). Until recently, more hunters pursued small game than any other category of game. As is true in the pursuit of nearly any recreation activity, small game hunters have a dedicated core of individuals. They hunt almost regardless of population changes among their preferred species. Consequently, declining small game populations associated with agricultural land has primarily affected the "incidental" small game hunter.

Though the number of small game hunters increased through 1975, the 1985 National Survey of Fishing, Hunting and Wildlife Associated Recreation (USDI Fish and Wildlife Service 1988b) indicated that small game hunting has since declined (table 16). The proportion of the U.S. population that hunted small game dropped by over 2% since 1975. Regional trends in the number of small game hunters have been declining in all assessment regions since 1980 with the greatest losses occurring in the North and South.

In the National Shooting Sports Foundation survey (1986), small game hunters attributed declining participation to several factors. Dwindling access to hunting land and crowded hunting areas were judged to be greater problems than in the past by 45% of the small game hunters polled, and the South was more greatly affected by these factors than other regions. Fifty-one percent of the hunters further indicated that game population declines were a greater problem than in the past. Insufficient game was a greater problem in the North (cited by 56% of the hunters), than in the South (43%), or the West (52%).

Small game harvest.—The harvest of small game generally represents between 10% and 30% of a species' annual population according to state agency data. There is a high degree of correlation between population size and number of small game harvested. Except for the Southern region, pheasant harvests generally have been declining throughout the nation. Quail harvests generally have dropped with some short-term increases in all but the Southern region. Rabbit harvests have declined consistently in all regions. Harvests of forest small game have been variable but a general increase is evident during the last 20 years.

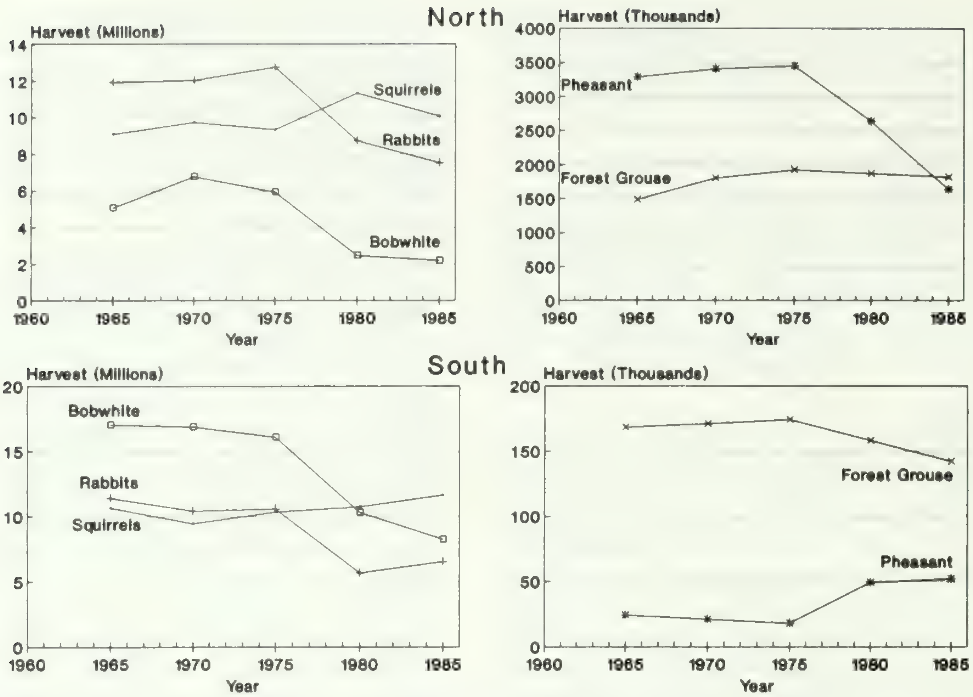
North.—Small game harvests in the North have declined for species associated with agricultural lands (fig. 24). An initial increase in bobwhite harvests during the early 1970's was followed by a consistent 15-year decline of over 65%. Pheasant harvests peaked in the mid-1970's, after which a 50% decline has been observed. Rabbits follow the same 20-year pattern noted for pheasants—slight increases in harvest through 1975 followed by a 40% decline by 1985.

Forest small game have not demonstrated the same pattern as agriculturally associated species (fig. 24). Squirrel harvests have steadily increased by 10% since the mid-1960's. Grouse harvests have been variable in recent history. For the six states which reported grouse harvests during 1965–75, no pattern was evident. During the 1975–1985 period, however, grouse harvests have increased in five states, and declined in three states. No particular geographic pattern to the states reporting increased or decreased grouse harvests is evident.

Table 16.—National and regional participation trends in small game hunting.[1]

Region	1965	1970	1975	1980	1985
			Thousands		
Total	10,576	11,671	14,182	12,496	11,130
(% population)	(7.5)	(7.5)	(8.3)	(6.8)	(5.7)
North				5,707	5,071
				(7)	(6)
South				4,766	4,140
				(9)	(7)
Rocky Mountain				1,534	1,387
				(12)	(10)
Pacific Coast				922	731
				(4)	(4)

[1]Regional totals do not sum to national totals since hunters may hunt in more than one state.
NOTE: Total participants based on people 12 years old and older. Regional participants in 1980 and 1985 are based on persons 16 years and older. For the purposes of trend analysis, the national figures reported here for 1965–1985 have been adjusted to permit comparison across years, as explained in appendix C of USDI Fish and Wildlife Service (1988b).
Source: USDI Fish and Wildlife Service (1988b); USDI Fish and Wildlife Service, and USDI Bureau of Census (1982).



NOTE.--Number of Northern states reporting harvest trends through 1985: Pheasant-9, Quail-6, Rabbits-7, Forest Grouse-9, Squirrels-7. Number of Southern states reporting harvest trends through 1985: Pheasant-2, Quail-7, Rabbits-7, Forest Grouse-3, Squirrels-6

Source: Data supplied by state fish and wildlife agencies

Figure 24.—Recent trends in small game harvests in the Northern and Southern regions.

South.—Pheasant harvests in the Southern region are heavily influenced by the estimates from the western and northern fringe states since pheasants do not occupy most of the region. Data from two southern states indicated increases in pheasant harvest since the mid-1970's (fig. 24)—a notable deviation from the significant declines observed in all other assessment regions. Northern bobwhite harvests have closely followed the trend in their populations with a consistent drop of over 50% during the last 20 years. The decline in rabbit harvests has been slightly more moderate than quail with a 40% drop being reported. Squirrel harvests declined slightly between 1965 and 1970 but have since recovered to levels that exceed those observed in 1965. In the three southern states reporting grouse harvests, the number of birds taken has declined by over 20% since 1975 and may be associated with the decline in early forest successional stages.

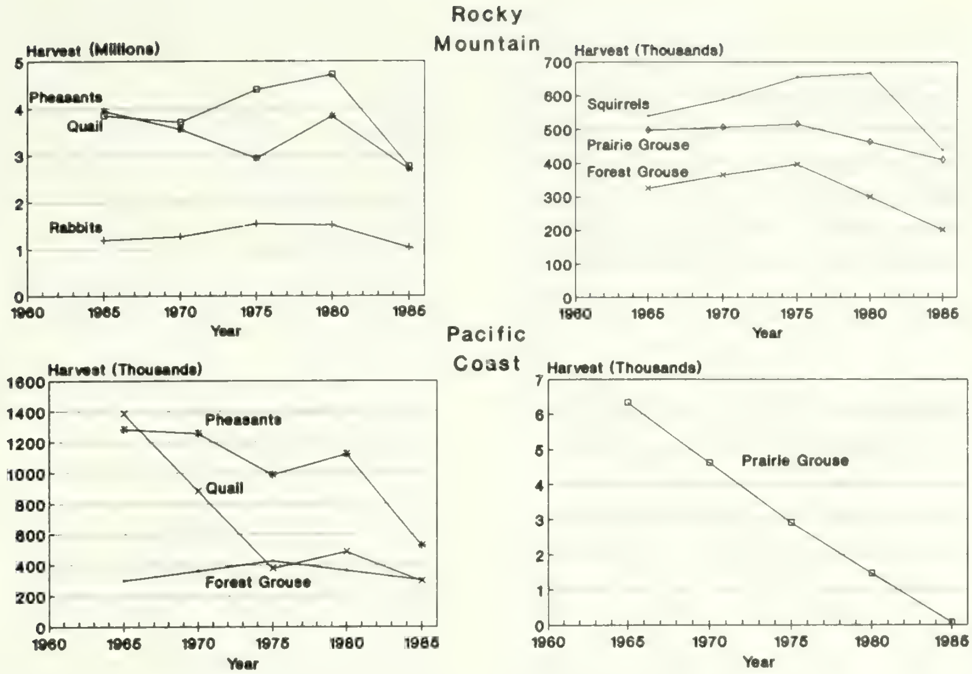
Rocky Mountain.—In general, small game harvests in the Rocky Mountain region have shown a convex pattern—increases through the mid-1970's and early 1980's followed by declines (fig. 25). Quail-harvest gains through 1980 have recently been lost. More recent harvests have dropped well below levels observed during the late 1960's and early 1970's. After increasing through the mid-1970's, rabbit harvests by 1985 had declined to 1965 harvest levels. The highest grouse harvests were experienced during the mid-1970's after which significant declines have been observed. Squirrel harvest increased by 18% by 1980, after which it dropped nearly 40% by 1985. Pheasant-harvest trends, an exception to the convex pattern in 20-year harvests, have declined by more than 30% since 1965.

Pacific Coast.—Obvious declines in pheasant and quail harvests have been observed in the Pacific Coast region since 1965. Pheasant harvests have declined by 60% while quail harvests have declined by 80% (fig. 25). After increasing through the mid-1970's, forest grouse harvests have declined to levels observed in the mid-1960's. Sage grouse harvests have declined dramatically since 1965.

Furbearers

Mammals referred to as furbearers constitute a wildlife resource valued not only ecologically and recreationally but also for income. Most furbearing animals are taken by trapping rather that hunting due to their secretive habits (Deems and Pursley 1983). This furtiveness makes information on population status difficult to collect. For most species, the only available information is on harvest levels, the trends of which may be more a reflection of fur price than of population status.

In addition to the information deficiencies on status and trends in the furbearer resource, trapping is further



NOTE.--Number of Rocky Mountain states reporting harvest trends through 1985: Pheasant-10, Quail-5, Rabbits-8, Prairie Grouse-10, Forest Grouse-9, Squirrels-3. Number of Pacific Coast states reporting harvest trends through 1985: Pheasant-3, Quail-2, Forest Grouse-3, Prairie Grouse-2

Source: Data supplied by state fish and wildlife agencies

Figure 25.—Recent trends in small game harvests in the Rocky Mountain and Pacific Coast regions.

characterized by long-term controversy. Trappers are under growing pressure to abandon their activity (Reiger 1978) to the extent that anti-trapping sentiment threatens the future of trapping in many areas of the country (Foner 1982; Linscombe, pers. comm., 1987).

Populations.—Few data on the population status of furbearers exist that are of sufficient scope and extent for use in national resource assessments. Two national summaries that have addressed furbearer population trends were completed by Deems and Pursley (1983) and Sisson-Lopez (1979). These reports provide qualitative indications of recent historical trends—the findings of which are summarized here. Only those species that are most commonly harvested, of significant economic value, or of particular public interest are reviewed.

The five furbearers most commonly harvested in the 1980's were the muskrat, raccoon, nutria, opossum, and beaver (Linscombe 1988). Muskrat populations have been, and continue to be, abundant throughout their North American range. Trends indicate fairly stable populations with short-term fluctuations tracking wetland habitat condition. One exception to this general trend was in the Rocky Mountain region where there was a gradual decline from 1955 to 1975 (Sisson-Lopez 1979), possibly reflecting diminishing wetlands.

The remaining four species have all shown recent population increases. The raccoon has become more numerous since the turn of the century, its adaptability reflected by increasing urban and suburban populations and by range extension to the north. Nutria, a rodent introduced from South America, has become so abundant in some areas that it is regarded as a pest. Now established in 15 states, the nutria raises concern about competition with native species such as the muskrat (Linscombe and Kinler 1985). Beavers are probably more abundant now than they were at the turn of the century (Deems and Pursley 1983). The few and isolated populations that existed in the early 1900's have expanded to include most of the beaver's original range. Transplanting programs, harvest regulations, and an abundance of suitable habitat are factors responsible for the observed increase. The Virginia opossum has been expanding its range northward; however, it remains most abundant in the South. A high reproductive rate, use of a broad range of land cover types, and adaptability have contributed to the opossum's increased distribution and abundance.

The red fox and mink are two additional species of interest because of their economic importance. In terms of total value (price per pelt x total harvest), the red fox

and mink were the fourth and fifth most valuable species in 1985, behind raccoon, muskrat, and beaver (Linscombe 1988). Recent trends for fox and mink are less favorable than for the more commonly harvested furbearers. Sisson-Lopez (1979) found evidence that both species had declining trends in some regions of the country. Fox declines appear associated with human pressures in the open prairie regions while mink declines may be tied to loss of important wetland habitats.

Two other species that warrant consideration because of high public interest are the coyote and bobcat. Because of depredation problems, the coyote has been a center for debate on predator control issues. Despite intensive control programs, coyote numbers appear to be increasing in many regions of the country. In addition, the coyote's range has been expanding eastward through northeastern (Moore and Millar 1984) and some southeastern states. Coyote range expansion probably results from elimination of the gray wolf, clearing of forests, agricultural practices, and adaptation to suburban environments (Carbyn 1982).

The bobcat became a species of particular public concern when pelt prices rose exponentially during the mid-1970's. The dramatic price increase followed high demand for spotted-fur garments when supplies were low due to restrictions on imported spotted-cat pelts. Because bobcats are susceptible to excessive hunting and trapping pressure (Koehler 1987), there was widespread public contention over the impact that increasing trapping pressure would have on the viability of bobcat populations. Part of the difficulty was a general dearth of information on bobcat abundance and ecology to accurately assess population status. Existing information suggests that bobcat populations increased during the 1950's and early 1960's but have since declined (Anderson 1987). The increase coincided with intensive control efforts to reduce coyote populations which are thought to compete with bobcats (Nunley 1978). Despite changes in abundance, the distribution of bobcats has changed little historically—exceptions include the midwestern and mid-Atlantic states where they have been eliminated from much of the area by intensive agricultural practices (Deems and Pursley 1983, Koehler 1987).

Trappers.—Trappers, themselves, share attributes of the species they pursue. Trappers tend to be withdrawn (Reiger 1978) and comprise a small percentage of the U.S. population, which makes studying their activity difficult. Unlike hunters, trappers have a profit motive attached to their activity. In addition to economic incentives, growing public and legislative pressures to eliminate trapping or restrict trapping methods affect trapper numbers. Many states have passed, or are considering, legislation that would outlaw trapping or significantly restrict where and how trapping is done.

Although regulations can affect participation in trapping, price is the dominant factor explaining recent trends in the number of trappers. There has been a strong correspondence between number of trappers and total fur value (fig. 26), and there is some indication of a 1-year lag in trapper response to prices. Based on data from

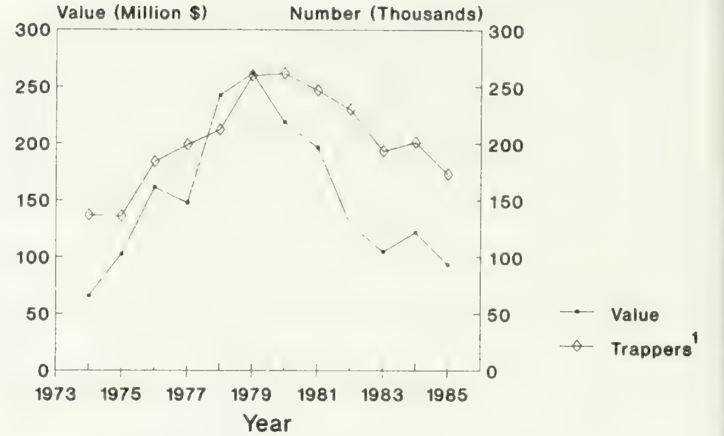


Figure 26.—Comparison of trends in total annual value of furs taken and the number of trappers from 1974–1985.

30 states, 1974–1985, trapper numbers peaked in 1980 after which numbers declined by nearly 35% (Linscombe 1988).

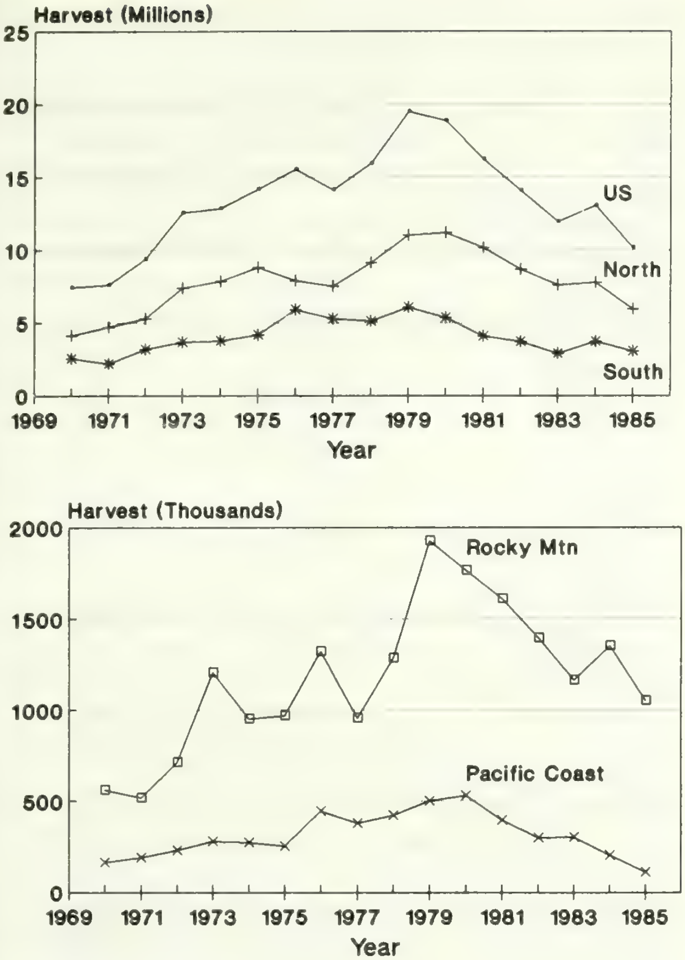
Furbearer Harvest.—Data on furbearer harvest trends are more complete than data on population levels or number of trappers. National harvest trends since 1970 correspond to the expected pattern given the value and trapper trends reviewed above. Number of furbearers harvested showed nearly a three-fold increase over the 1970–1980 period. However, by 1985, furbearer harvest had been halved from peak levels (fig. 27). This pattern is consistent within each assessment region, with peak harvests all occurring during the 1979–1980 period.

Harvest trends for the five most commonly harvested furbearers show only minor deviations from the total harvest trend (fig. 28). The greatest relative declines since the late 1970's have occurred with muskrat, nutria, and opossum—all declining by over 60%. Raccoon harvests have declined at a more moderate rate while beaver harvests have actually increased since 1983.

Prices that trappers have received per pelt are a strong determinant of harvest. From 1978 to 1985 the average price per pelt dropped by nearly 40% (fig. 29). In constant (accounting for inflation) 1974 dollars, the gross return realized by trappers has declined by 61% over the same period. Unless consumer demand for natural fur garments increases, or new foreign markets are found, these trends will not likely reverse in the near future.

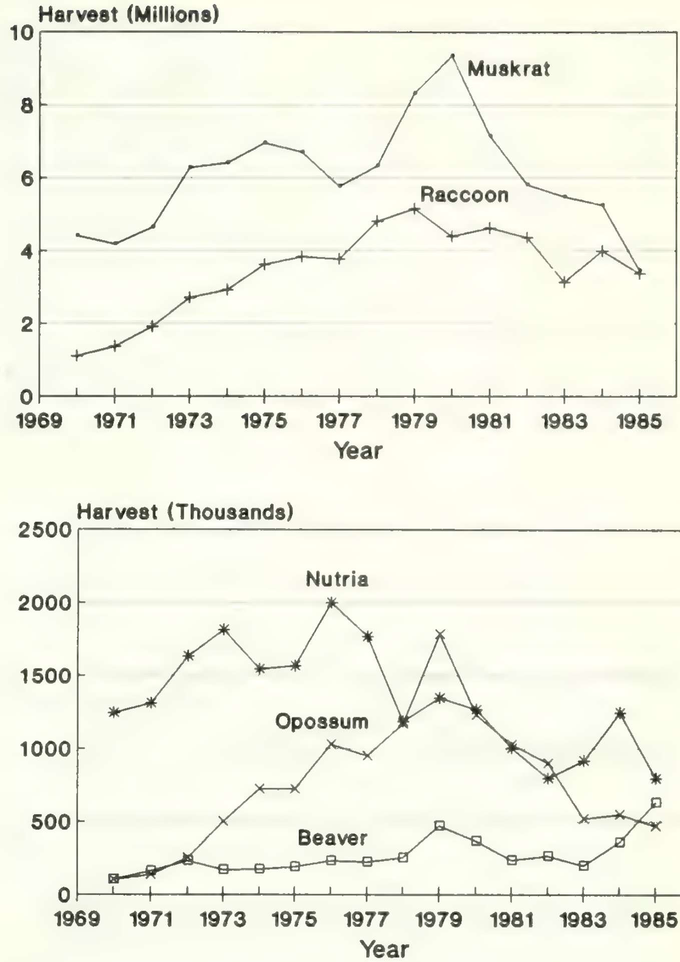
Fish

Fish species in the United States are found in a variety of aquatic habitats from inland rivers, streams, lakes, pond and reservoirs, to estuaries and open marine environments. Both the freshwater and marine fishery resource have extremely important economic, recreational, and environmental value. Maintenance and improvement of the nation's fisheries benefit human health and nutrition, economic prosperity, and leisure enjoyment (Gordon 1988). In 1986 alone, the 239,000 people who engaged in commercial fishing took approximately 6 billion pounds valued at $2.8 billion (USDC



Source: Linscombe (1988)

Figure 27.—Trends in total fur harvest for the nation and by assessment region from 1970–1985.



Source: Linscombe (1988)

Figure 28.—Harvest trends for the five most commonly harvested furbearers (1970–1985).

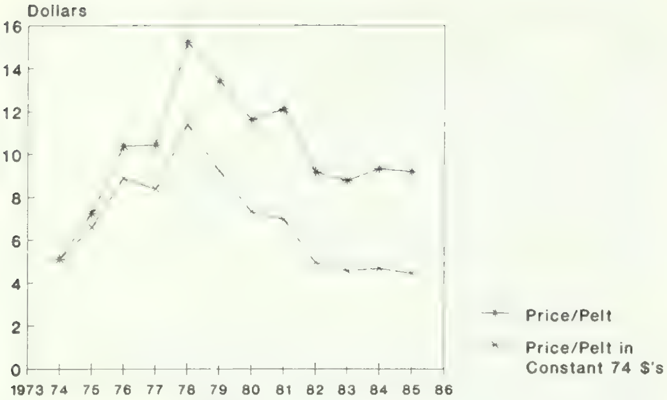
National Oceanic and Atmospheric Administration, National Marine Fisheries Service 1987). In addition, the Fish and Wildlife Service (1988b) found that more than one out of every four persons in the United States fished in 1985.

Despite the importance of the nation's fisheries as sources of recreation and livelihood, little information exists that can be used to identify or evaluate changes in fish species distribution and abundance. Information on trends in the number of users and commercial harvest are more complete. Recreational use is monitored by the Fish and Wildlife Service and commercial users and harvests are monitored by the National Marine Fishery Service. This report focuses on that portion of the fishery resource that is potentially impacted by land management activities. Consequently, emphasis is placed on inland and anadromous fish species with less consideration of marine species.

Populations.—The numbers of fish in the nation's lakes, streams, reservoirs, and estuaries are rarely inventoried except at specific locales. Although many population surveys have been completed, generally it is not possible to extrapolate beyond the specific area sampled. Only one known study provides estimates of the nation's fishery population resources. The distribution and abundance of the nation's fish resources were considered as a part of the 1982 National Fisheries Survey (Judy et al. 1984). Fish were categorized as sport and nonsport species and related to the number of miles of streams in which they occurred.

Sport fish species occurred in 73% of the nation's streams while nonsport species were found in 68%. Twenty-one percent of all streams sampled contained no fish largely due to lack of water in intermittent streams. Anadromous sport fish species were present in 11% and commercial fish species were found in 17% of the stream miles sampled. Defined in terms of stream miles occupied, largemouth bass and carp were the most widely distributed sport and nonsport species, respectively (table 17).

Given the distribution of the fisheries resource described above, Judy et al. (1984) went on to classify sport and nonsport fish into five abundance categories: abundant, common, uncommon, rare, and expected. The survey found 64% of the stream miles sampled to be suitable (i.e., support an abundance class of abundant



Source: Linscombe (1988)

Figure 29.—Trends in average price per pelt from 1974–1985.

or common) for sport fish while sport fish were uncommon or rare in only 7% of the stream miles sampled (table 18). Sport fish were found to occupy the greatest number of stream miles in the common category (41%) while nonsport fish occupy the most miles of stream in the abundant category.

Evaluating these statements is difficult without a second point of reference either in terms of data from a previous time or an explanation of the factors that produced the results. Attempting to address recent trends in the condition of the freshwater fishery resource, Judy et al. (1984) asked biologists to rate the ability of the nation's waters to support fish communities over a 5-year period. The results indicated little change—4% of the streams improved, 5% were diminished, and 91% of the streams remained unchanged in their ability to support fish communities.

Longer trends in the distribution and abundance of some fish species are available only from specific regional studies. In New England, the plight of the Atlantic salmon is, in many respects, indicative of trends in other anadromous salmonids. Beland (1984) estimated that in precolonial times, as many as 500,000 returning adult Atlantic salmon migrated up 34 river systems. The USDI Fish and Wildlife Service (1984) estimated that 7,000 adult salmon now enter only 16 New England river systems. Of the total returning adult spawners, only about 1,000 are from natural reproduction—the remainder being from hatchery stock.

The factors responsible for the Atlantic salmon decline are varied. Commercial harvests have been cited in the species' early decline (New England Fishery Management Council 1987), and harvest continues to limit recovery. Boreman et al. (1984) estimated that for every adult salmon returning to New England rivers, one to five are caught in the ocean fishery. Despite the mortality associated with commercial harvests, probably the most limiting factor has been inaccessible spawning and nursery habitat caused by dams lacking fish passage structures. Beland (1984), Oatis et al. (1985), and Stolte (1982) estimated that on the six major river systems under restoration, less that 50% of the potential spawning and nursery habitat is accessible to returning adults.

Similar factors have been implicated in the decline of chinook salmon in the Columbia River basin. Although many salmonid species inhabit the Columbia River basin, the chinook is perhaps the most economically, culturally, and politically important (Phinney 1986). Examination of commercial and recreational catches, dam counts, and hatchery returns provides minimum estimate of in-river runs of salmon. Trends since 1965 indicate that lower-river chinook runs have shown significant improvement because of increased hatchery production. Conversely, upper-river runs have declined sharply (fig. 30). The cumulative impact of hydroelectric

Table 17.—Ten most prevalent sport and nonsport fish species occurring in the nation's waters.

Species	Stream miles where species occurred	Percentage of total stream miles
Sport fish species		
Largemouth bass	263,859	27.3
Rainbow trout	213,461	22.1
Bluegill	188,495	19.5
Channel catfish	148,343	15.4
Smallmouth bass	142,142	14.7
Green sunfish	126,074	13.1
Brook trout	103,507	10.7
Black crappie	98,190	10.2
Spotted bass	98,129	10.2
Rock bass	94,682	9.8
Nonsport fish species		
Common carp	187,417	19.4
Creek chub	176,709	18.3
White sucker	166,823	17.3
Gizzard shad	131,730	13.6
Bluntnose minnow	126,665	13.1
Stoneroller	122,337	12.7
Green sunfish	115,234	11.9
Common shiner	112,112	11.6
Fathead minnow	110,531	11.4
Golden shiner	106,602	11.0

Source: Judy et al. (1984).

Table 18.—National estimates of fish class abundance for "all streams."

Fish class abundance	Stream miles in class	Percentage of total stream miles
Sport fish		
Abundant	221,694	23.0
Common	391,757	40.6
Uncommon	52,582	5.5
Rare	12,228	1.3
Expected	65,619	6.8
Nonsport fish		
Abundant	334,700	35.1
Common	303,713	31.9
Uncommon	22,344	2.3
Rare	4,727	0.5
Expected	60,414	6.3

Source: Judy et al. (1984).

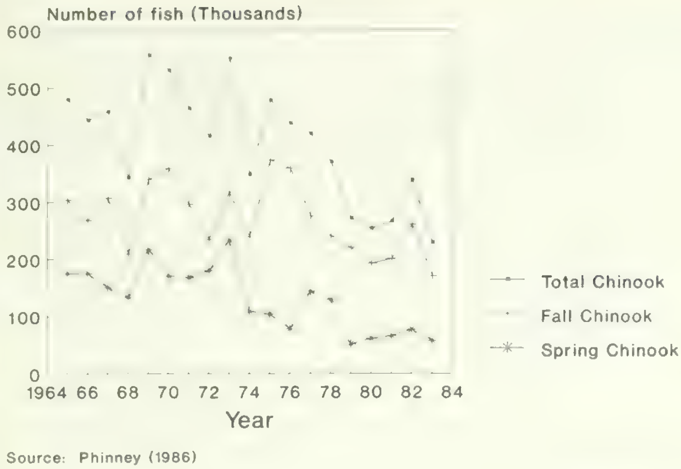


Figure 30.—Trends in upper-river chinook salmon returns in the Columbia River Basin, 1965–1983.

projects is certainly a major obstacle to chinook runs; however, excessive ocean and in-river fishing rates have also contributed to the decline (Phinney 1986).

Some resident salmonids have also suffered range restrictions and population declines. In the Appalachian region of Tennessee, brook trout only occupy 20% to 30% of their estimated range at the turn of the century (Bivens et al. 1985). Severe range restrictions and population declines have also been noted in many native western trout species (Behnke and Zarn 1976). Hybridization and competition with nonnative salmonids have contributed to the decline in both the eastern and western trout populations. Habitat degradation resulting from irrigation projects, mining, logging, road construction, and overgrazing has also been an important factor in the demise of these native trout populations.

The negative impacts on the nation's fishery resources associated with human development are not restricted to coldwater species. In the agriculturally dominated landscapes of the Midwest, warmwater fish communities have deteriorated significantly. Karr et al. (1985) documented that since the mid-1800's 67% of Illinois River fish species and 44% of Maumee River species have experienced population declines or have been eliminated. Human activities that have had the greatest impact on these warmwater fish communities include: lowered water tables and nutrient enrichment associated with agricultural development; construction of navigational locks, channels, levees, milldams, and other impoundments; discharge of oxygen-demanding wastes and toxic chemicals; excessive water consumption; and introduction of exotic species (Karr et al. 1985).

Recreational and commercial fishers.—The number of people pursuing recreational fishing has been increasing over the last 20 years, although the trend varies by type of fishing (table 19). Freshwater fishing represented 86% of the total number of anglers in the United States in 1985, and the number of freshwater anglers has increased consistently since 1965. The number of saltwater anglers has recently increased after a decline in participation in 1980.

There are some regional differences in the trends of sport anglers (table 20). The number of anglers has consistently increased in all regions except the North where a decline of nearly 1 million anglers occurred between 1975 and 1980. Since 1980, however, fishing participation in the North has increased back to levels observed in 1975. In the South and Rocky Mountain regions, a higher percentage of the population fishes than in the North and Pacific Coast regions. It might be expected that outdoor recreationists in the East would be increasingly attracted to fishing over hunting because of less restrictive regulations and greater accessibility.

The number of commercial fishers is largely governed by the availability of fish stocks and markets for the catch. The demand for edible fish products has increased significantly. From 1965 to 1985, the per capita consumption of fish increased by nearly 35% (Bunch 1985). Accompanying this noted increase in demand has been a significant influx of commercial fishers. In 1985, there were 80% more commercial fishers in the United States than 20 years earlier (fig. 31).

Commercial fish harvest.—State agencies estimate recreational harvest through creel census methods which tend to be site specific. There are no known national or regional summaries of creel-census information although there are now individual states that are developing standardized data summaries for their fisheries. The National Recreational Fisheries Policy (USDI Fish and

Table 19.—Total freshwater and saltwater anglers and days of fishing (1965–1985).

Year	Freshwater anglers			Saltwater anglers			All anglers		
	Number (thousands)	% of U.S. population	Days of fishing (thousands)	Number (thousands)	% of U.S. population	Days of fishing (thousands)	Number (thousands)	% of U.S. population	Days of fishing (thousands)
1965	23,962	16.9	426,922	8,305	5.9	95,837	28,348	20.0	522,759
1970	29,363	18.9	592,494	9,460	6.1	113,694	33,158	21.4	706,187
1975	36,599	21.3	890,576	13,738	8.0	167,499	41,299	24.0	1,058,075
1980	35,782	19.4	788,392	11,972	6.5	164,040	41,873	22.7	952,420
1985	39,122	20.0	895,027	12,893	6.6	171,055	45,345	23.2	1,064,486

NOTE: Total participants based on people 12 years old and older. For the purposes of trend analysis the figures reported for 1965–1985 have been adjusted to permit comparison across years, as explained in appendix C of USDI Fish and Wildlife Service (1988b).
Source: USDI Fish and Wildlife Service (1988b).

Table 20.—Number and percent of the U.S. population sport fishing by assessment region (1965–1985).

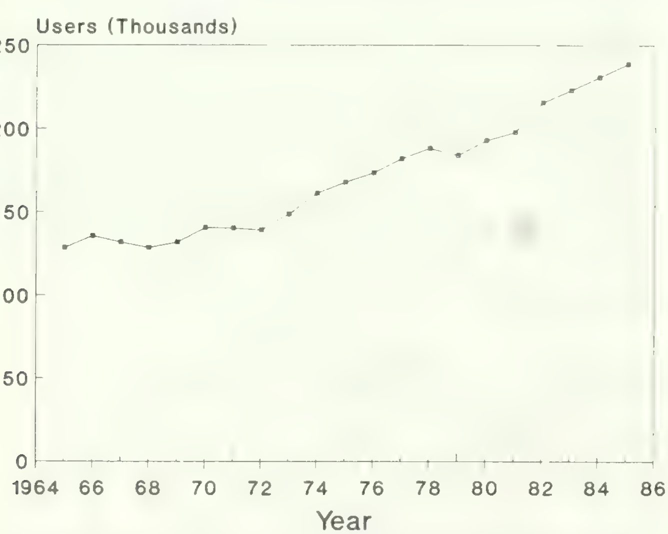
Year	North[1]		South[2]		Rocky Mountain[3]		Pacific Coast	
	Number (thousands)	% of U.S. population	Number (thousands)	% of U.S. population	Number (thousands)	% of U.S. population	Number (thousands)	% of U.S. population
1965	12,810	16.8	10,533	24.5	1,261	25.1	3,744	21.4
1970	16,212	20.2	11,599	22.8	1,769	31.3	4,030	20.0
1975	19,228	22.2	14,435	26.5	2,252	29.7	5,386	23.4
1980	18,231	20.7	15,395	25.1	2,500	27.3	5,747	21.9
1985	19,685	22.0	17,068	25.4	2,765	27.1	5,829	20.3

[1]*Includes the states of ND, SD, NE, KS and excludes MD, WV, and DE.*
[2]*Includes the states of MD, WV, and DE.*
[3]*Excludes the states of ND, SD, NE, and KS.*
NOTE: Total participants based on people 12 years old and older. For the purposes of trend analysis the figures reported for 1965–1985 have been adjusted to permit comparison across years, as explained in appendix C of USDI Fish and Wildlife Service (1988b).
Source: USDI Fish and Wildlife Service (1988b).

Wildlife Service 1988c) recommends developing a consistent and comprehensive system for collecting, storing, and retrieving recreational fisheries harvest information. Implementation of this policy would significantly improve the capability to monitor the status of the nation's fishery resource. In the absence of a consistent regional or national information base, little can be said about the amount of fish harvested by recreational anglers.

Commercial fish harvest is reported annually by the National Marine Fisheries Service. Several species or species groups of commercial fish live in the nation's lakes, streams, and estuaries and are influenced by land-management practices. The discussion that follows will emphasize these species.

Domestic harvests of salmon vary in relation to a number of complex and interacting factors including the quality of the run (determined by weather, survival, etc); subsistence fishing pressure from Native Americans; regulations on species, gear, and particular fishing grounds; and finally, pelagic harvests from foreign-flag vessels. Commercial harvest of salmon for the nation averaged approximately 300 million pounds during the late 1960's, dropped to about 200 million pounds in 1975, and increased to a high of around 730 million pounds in 1985 (fig. 32), valued at nearly $440 million.



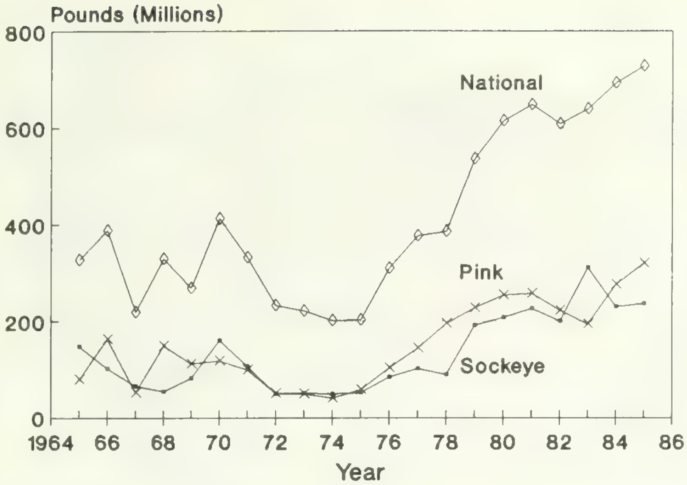
Source: USDI, Bureau of Commercial Fisheries (1967-1969); USDC, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (1971-1975, 1976a, 1976b, 1977, 1978,1979, 1980a, 1980b, 1981-1983, 1984a, 1984b, 1985-1987)

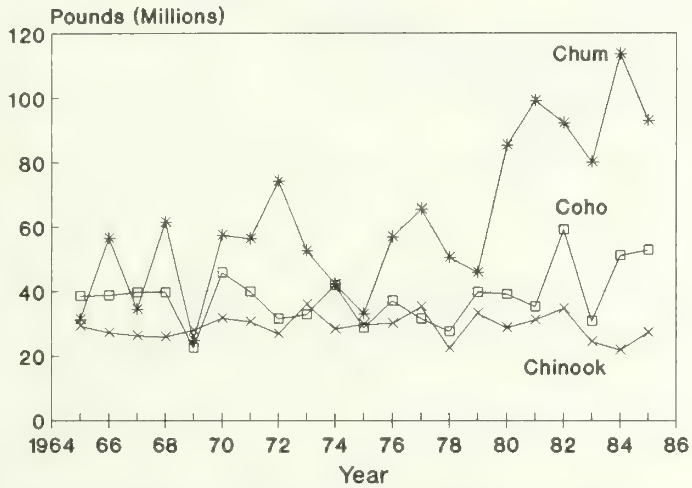
Figure 31.—National trends in numbers of commercial fishers, 1965–1985.

The 1966 harvest represented a record high for the previous 20 years indicating that recent historical trends in harvest have increased substantially. The increasing harvest was, in part, a response to escalated domestic and foreign demand. Between 1975 and 1985, domestic per capita consumption of canned salmon products doubled from 0.3 pounds to 0.6 pounds (Bunch 1985); and exports of salmon increased nearly five-fold from 71,000 pounds to 338,000 pounds (USDC National Oceanic and Atmospheric Administration, National Marine Fisheries Service 1976b, 1986). Despite increasing demands, the average value per pound since the last assessment has declined by 43% (57.7 cents/pound in 1975 to 32.8 cents/pound in 1985, in constant 1975 dollars).

The salmon harvest comes almost exclusively from the Pacific Northwest and Alaska. The national contribution of the Great Lakes commercial salmon fishery is minor, and the Atlantic salmon fishery is still recovering from a long history of overharvest and blocked access to breeding habitats by waterway projects (Stolte 1986).

The trends of individual salmon species are important because of the differences that exist in their life histories, harvest, and habitat situations. Pink and sockeye salmon are the most heavily harvested species followed by chum, and then considerably smaller amounts of chinook and coho (fig. 32). Harvests of pink, sockeye, and to a lesser extent chum, salmon have increased over the recent historical period while chinook and coho salmon have remained at a relatively stable harvest level. Poor runs of pink and sockeye salmon in the early 1970's probably resulted from severe winters in 1970–1972 and





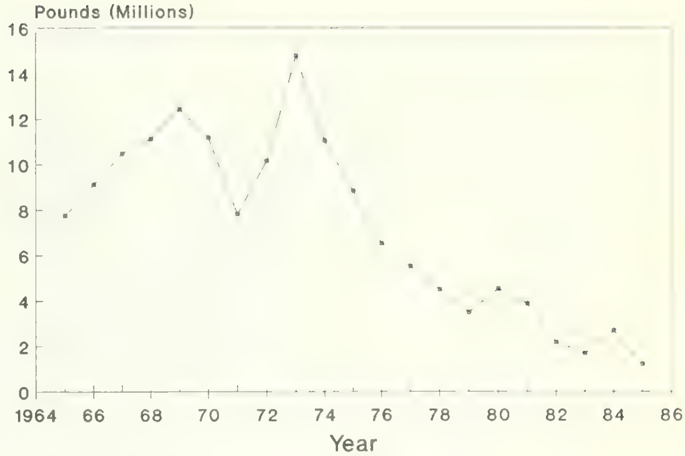
Source: USDI, Bureau of Commercial Fisheries (1967-1969); USDC, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (1971-1975, 1976a, 1976b, 1977, 1978, 1979, 1980a, 1980b, 1981-1983, 1984a 1984b, 1985-1987);

Figure 32.—Commercial harvest of salmon by species nationwide, 1965–1985.

heavy pelagic harvests; however, improved weather conditions in subsequent years improved the runs and the harvest for these species.

In addition to the salmon, steelhead trout are commercially harvested in the Pacific Northwest. The record of commercial landings of steelhead during the 1965–1977 period is one of considerable variation with the number of pounds varying between 250,000 and 700,000 from one year to the next.

The striped bass, historically a species of the North American Atlantic coast, has been transplanted to the Pacific Coast plus many freshwater lakes and streams. In its original range, overharvest, chemical contamination, declining pH levels, and dams have combined to significantly reduce population levels (Fosburgh 1985a). The commercial harvests of striped bass have dropped dramatically since the early 1970's. Attempts to institute a moratorium on commercial harvests have been unsuccessful and the commercial harvest shown in figure 33 primarily represents the remaining Atlantic Coast use.



Source: USDI, Bureau of Commercial Fisheries (1967-1969); USDC, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (1971-1975, 1976a, 1976b, 1977, 1978, 1979, 1980a, 1980b, 1981-1983, 1984a, 1984b, 1985-1987)

Figure 33.—Commercial harvest of striped bass nationwide, 1965–1985.

A large number of freshwater finfish are commercially harvested in various lakes and streams and include bullhead, catfish, yellow perch, crappie, walleye, sauger, and pike. During the late 1970's, freshwater finfish harvests fluctuated between 80 and 90 million pounds. In 1980, freshwater commercial harvests increased dramatically to about 130 million pounds, after which harvests have stabilized near 120 million pounds. The amount of freshwater finfish harvested commercially depends largely on the demand for fish which expanded in recent years with a stabilized per capita demand for red meat (Joyce in press).

Other commercial fisheries associated with large rivers and estuarine environments include the shellfish. These species are critically influenced by land and water management practices. Shellfish harvests have fluctuated around 1 billion pounds over the last 15 years (fig. 34). The total commercial crab harvest nearly doubled between 1971 and 1980, falling back to earlier levels by 1985. Blue crabs were at their lowest harvest levels in the late 1960's and early 1970's but increased during the mid-1980's. The higher harvest of shellfish in the late 1970's and early 1980's was primarily the result of increases in the shrimp harvest. Blue, snow, and king crabs were largely responsible for the increase in crab harvests observed in the late 1970's.

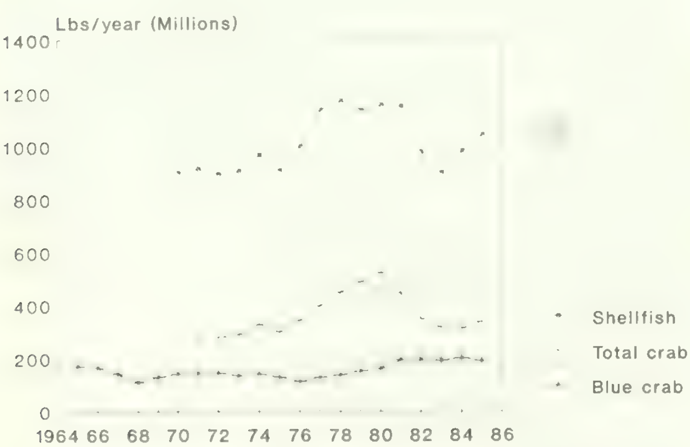
Threatened and Endangered Species

Individual species are a tentative signature on the genetic composition of the earth. Over the last 20 years, however, the rate at which species are now being lost has generated much concern. In a review of global extinctions, Flesness (1986) conservatively estimated a six-fold increase (0.124 species/year to 0.767 species/year) in the vertebrate species extinction rate occurred in the periods 1600–1825 and 1826–1975.

Since the turn of the century, a determined effort has been made to reduce the impact that man has on the rate of animal species extinctions. Early treaties between the United States and other nations such as Canada, Mexico, England, and Russia attempted to reduce excessive exploitation of animal populations. However, not until 1966, under the Endangered Species Preservation Act, did the United States adopt legislation specifically addressing the protection of endangered species. New legislation that improved on the identified flaws in the earlier statute was enacted in 1969 (the Endangered Species Conservation Act) and in 1973 (the Endangered Species Act), the latter being amended in 1978, 1982, and 1988. Two status categories are recognized: *endangered*, which covers species in danger of extinction throughout all or significant parts of their ranges; and *threatened*, which includes species likely to become endangered within the foreseeable future throughout all or significant parts of their ranges.

Many states have comparable endangered species programs directed at preserving species within state boundaries. Under current federal legislation, state programs are eligible for federal matching dollars of up to 75% of program costs. This series of federal and state laws established the requirement for all federal and participating state agencies to conserve endangered wildlife and fish through restrictions on activities that jeopardize continued existence, or the implementation of management programs that are directed ultimately at population restoration.

Number and distribution.—The number of species officially considered threatened and endangered is monitored by the Fish and Wildlife Service and reported monthly in the Endangered Species Technical Bulletin. Since the last national assessment of wildlife and fish, the number of listed species has increased in every animal class (table 21). Interpretation of this increase is difficult since there is a continual process of adding and



Source: USDI, Bureau of Commercial Fisheries (1967-1969); USDC, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (1971-1975, 1976a, 1976b, 1977, 1978, 1979, 1980a, 1980b, 1981-1983, 1984a, 1984b, 1985-1987)

Figure 34.—Commercial harvest of shellfish nationwide, 1965–1985.

Table 21.—Number of threatened and endangered animal species.

Category	Endangered 1988	Threatened 1988	Total 1988	Total 1980
Mammals	50	7	57	25
Birds	76	10	86	70
Reptiles	15	18	33	18
Amphibians	5	4	9	7
Fish	47	30	77	41
Invertebrates	55	13	68	39
Total	248	82	330	200

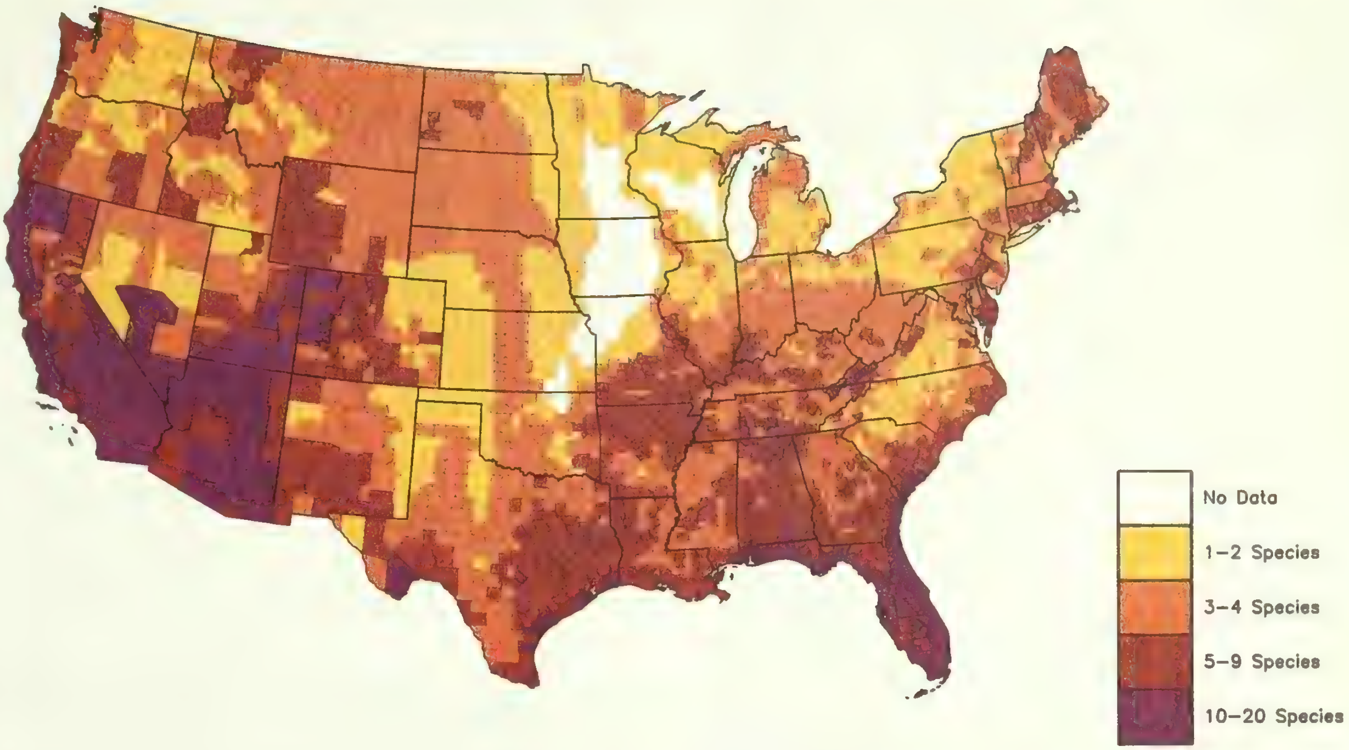
Source: USDA Forest Service (1981); USDI Fish and Wildlife Service (1988a).

deleting species from the list. New information regarding the status of listed and unlisted species is continually being evaluated. While more listed species may mean more species have become endangered, it may also mean evaluation has been completed for candidate species. Currently, the Fish and Wildlife Service has sufficient information to initiate formal listing procedures for approximately 1,000 candidate plant and animal species (Bean 1986).

Although the number of species listed and the rate with which listing has taken place is difficult to interpret from an ecological standpoint, the distribution of these species by county is valuable for interpreting how threatened and endangered species relate to the major biomes of the United States (fig. 35). Areas with major modification of natural environments have greater concentrations of threatened and endangered species, such as in the sun belt and coastal counties. Also, areas with sensitive desert environments have high numbers of threatened and endangered species. This is explained, in part, by the number of animals that live within refugia (primarily unique aquatic habitats) in otherwise harsh environments.

By definition, the populations of threatened and endangered species are low; however, very little information on the population levels of most endangered species exists. For this reason, we chose to consider the status of endangered species in two categories: those that are recovering, and those that have not improved since they were listed. Examples of species that have been recovering include the American alligator, peregrine falcon, southern sea otter, and Puerto Rican parrot; species such as the California condor, black-footed ferret, and the red-cockaded woodpecker have not been increasing.

Recovering species.—The fact that there have been few complete recoveries is not surprising given the short existence of protective legislation. However, even in the 20-year period of endangered species legislation some species have responded favorably to protection. The American alligator was in danger primarily because of overharvesting. Since its listing, the alligator has recovered sufficiently to be removed from the federal threatened and endangered list (USDI Fish and Wildlife Service 1987b), and in many areas, strictly regulated annual harvests for economic purposes continue to increase.



Source: Oak Ridge National Laboratory (pers. comm. 1981)

Figure 35.—Distribution of federal threatened and endangered species by counties in the United States.

The peregrine falcon was placed on the threatened and endangered list because organochlorine pesticides inhibited its reproductive success. The pesticides caused thin egg shells which broke during incubation or, in dry climates, allowed embryos to desiccate before hatching. The banning of pesticides such as DDT in conjunction with a captive breeding program was instrumental in recovery success. The tundra peregrine has recovered to the point where it was "downlisted" to threatened status in 1983 (USDI Fish and Wildlife Service 1983). Despite such success, however, the peregrine will probably remain on the threatened and endangered list until organochlorine pesticides are completely eliminated from the peregrine's range, including Latin America (Craig 1986).

The southern sea otter, like the alligator, was an overexploited species. Protection afforded the species by its listing as endangered increased the probability of successful reintroduction aimed at establishing viable populations along the coasts of California and Oregon (USDI Fish and Wildlife Service 1986a). Implementation of several important recovery tasks has given researchers reason to believe that annual population increases on the order of 4% to 5% can be expected (Ladd and Riedman 1987).

The Puerto Rican parrot was listed because of habitat reductions and exploitation of the bird as a pet (MacPherson 1987). Listing has controlled exploitation and provided the impetus for habitat improvements needed for the species to attain viability. From a low of 13 individuals in 1975, the population has grown to 41 individuals today (MacPherson 1987).

Declining species.—The California condor has frustrated the attempts of those involved in its recovery because of habitat degradation and low breeding potential. The condor population has declined in spite of breeding programs and research efforts to learn more about the bird's habitat requirements. As of 1984, only 15 birds were known to exist in the wild (Bean 1986), and in a final effort to retain what little genetic variability existed, all known individuals were captured and placed in a captive breeding program.

The black-footed ferret was listed largely because of its low population resulting from habitat degradation including a declining prey base (prairie dogs). The secretive habits of the species, low population, and failures associated with captive breeding have disappointed researchers trying to assist the species' recovery. The dramatic reduction of a recently located breeding population in Wyoming from 128 to 16 individuals caused by an outbreak of distemper (Williams et al. 1988), emphasized the vulnerability of isolated populations.

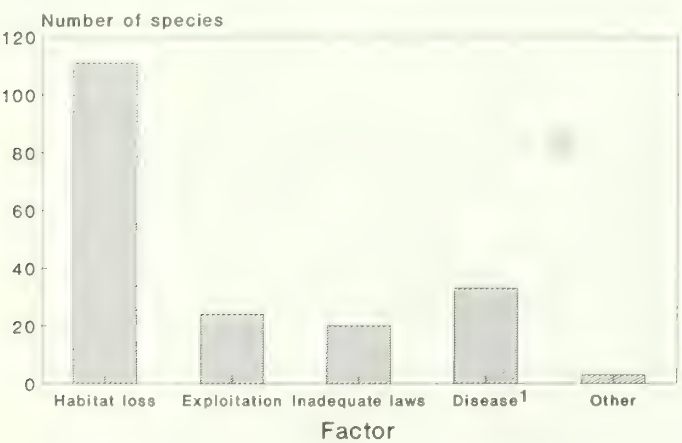
The red-cockaded woodpecker is on the threatened and endangered species list primarily because its habitat has been deteriorating through loss of older loblolly/shortleaf and longleaf/slash pine forests under which fires frequently burn to reduce the hardwood understory (Lennartz and McClure 1979). The woodpecker continues to decline because the amount of habitat that meets its specialized habitat requirements continues to

decline. No known subpopulation of red-cockaded woodpeckers is increasing or stable, and its long-term survival seems heavily dependent on public land ownerships (Jackson 1987).

Relationship between population declines and land types.—Early on, scientists concerned about threatened and endangered species identified the major factors contributing to species endangerment. A consistent factor for many species was man-induced loss or degradation of habitat. Other major causes include disease, excessive harvest, and inadequate protection from human disturbance. Figure 36 indicates the relative importance of the factors contributing to animal species becoming threatened or endangered based on data in the Fish and Wildlife Service's Endangered Species Information System (USDI Fish and Wildlife Service 1987c).

An attempt to compare threatened and endangered species with habitat yields figure 37. Though such a chart may help a person visualize how species status relates to habitat status (as described in earlier sections), interpretation must be done with caution. Simple associations do not convey full natural history or ecological processes. The utility of this information, like so much of the material presented in this assessment, is to provide a broad perspective for organizing policies and management decisions rather than for recommending specific land management actions. Understanding these constraints should assist in obtaining useful insight from figure 37.

For example, a high number of threatened or endangered species associate with urbanland, primarily because urbanland uses superimpose other land types and represent a drastic modification of the original habitats. For some species, urbanland represent a significant mortality factor attributable to the nation's extensive transportation network. But many threatened and endangered species are also associated with agricultural land types which have disturbed and fragmented forest and range ecosystems.

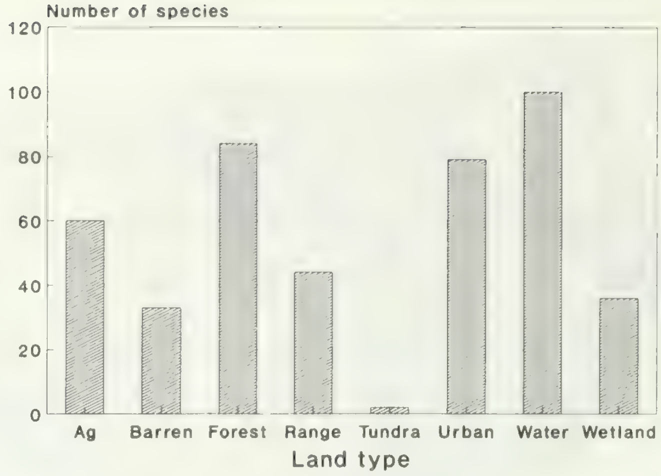


[1]Includes predation

NOTE.--Based on 116 animal species

Source: USDI, Fish and Wildlife Service (1987c)

Figure 36.—Factors contributing to animal species being threatened or endangered.



NOTE.--Based on 116 animal species. Number of species across land types do not sum to 116 because species are represented in more than one land type

Source: USDI, Fish and Wildlife Service (1987c)

Figure 37.—Number of threatened and endangered animal species associated with land types for the United States.

In the case of natural habitats, the number of endangered species comes from the original and potential diversity of the land type. Hence, forest and water/ wetland types contain the greatest numbers of endangered species because they also contain the largest number of species. Tundra on the other hand is a harsh, less diverse environment with a relatively small list of endangered and associated species.

Summary

The current status of and recent historical trends in populations and uses of wildlife and fish resources are related to trends in their habitats. Species associated with agricultural, mature and old-growth forest, native grassland, and wetland environments have had declining or unstable populations in the last 20 years. Breeding birds that have shown recent population declines are more numerous in the East than in the West. Breeding birds that have increased tend to be those adapted to more intensive land uses, particularly urban/suburban environments. Population trends in game species have varied. With the exception of geese, migratory game bird populations have declined. Big game species across all regions have shown recent population increases with the exception of deer in the Pacific Coast region. Small game population trends differ between agriculture and forestland. Those small game species associated with agricultural lands have shown significant declines over the last 20 years, while most forest small game populations have remained stable or increased. Trends in furbearer populations have varied—the most commonly harvested species have stable or increasing populations, while other species such as red fox and mink have shown

regional declines. While there is limited quantitative information on how the nation's fish communities have changed, specific regional studies help. Generally, the capacity of the nation's waters to support healthy warmwater and coldwater fisheries has declined in response to anthropogenic degradation of aquatic habitats and introductions of competing fish species.

Recent trends in the recreational use of wildlife and fish are a function of the availability of wildlife and fish resources and the public's relative preference for different kinds of recreational activities. Nonconsumptive recreation has increased at a substantially greater rate than other forms of wildlife and fish recreation. Most of the increase in nonconsumptive recreation occurs with activities in and around people's residences or in association with their other outdoor activities. The number of persons that actually took trips for the sole purpose of viewing wildlife has not kept pace with the increase in U.S. human population. Though the number of big game hunters has generally increased during the last 20 years, the number of small game and migratory game bird hunters has declined, a probable response to lower game populations, reduced access, and crowded hunting conditions. The number of trappers has recently declined in apparent response to low prices, but fewer trappers may also reflect public and legislative pressure to restrict this activity. Both recreational and commercial fishers' numbers have consistently increased during the last 20 years.

Recent historical trends in game harvests reflect a combination of animal population levels and hunter effort, and in the case of furbearers, price. Consequently, the harvest trends noted are consistent with the population and user characteristics summarized above. Notable exceptions to this expected relationship concerns ducks in the Mississippi and Atlantic flyways which have shown stable harvests despite a declining number of hunters and duck populations.

The recent historical trends summarized reflect the wildlife and fish resource situation on all lands. No distinction has been made regarding resource trends within specific ownership categories. To evaluate the potential effectiveness of future Forest Service programs in managing natural resources, a review of the recent resource situation on public lands is required.

WILDLIFE AND FISH RESOURCES ON PUBLIC LANDS

The public generally perceives that public lands have attained the stature that the early conservationists such as Roosevelt, Pinchot and others had in mind when they began establishing the National Forest System, the National Park System, and the National Wildlife Refuge System. Some conservation and management success on public land is evident: large ungulate populations, critical habitat for threatened and endangered species, large predator populations, and a general uniqueness of local faunas. Partially as a result of federal laws, federal agencies have greatly improved inventory data, analytical methods, management policies, and management practices. Using all these, managers attempt to maintain viable populations, habitat diversity, and species diversity in concert with the full complement of other values associated with managed forest and range ecosystems.

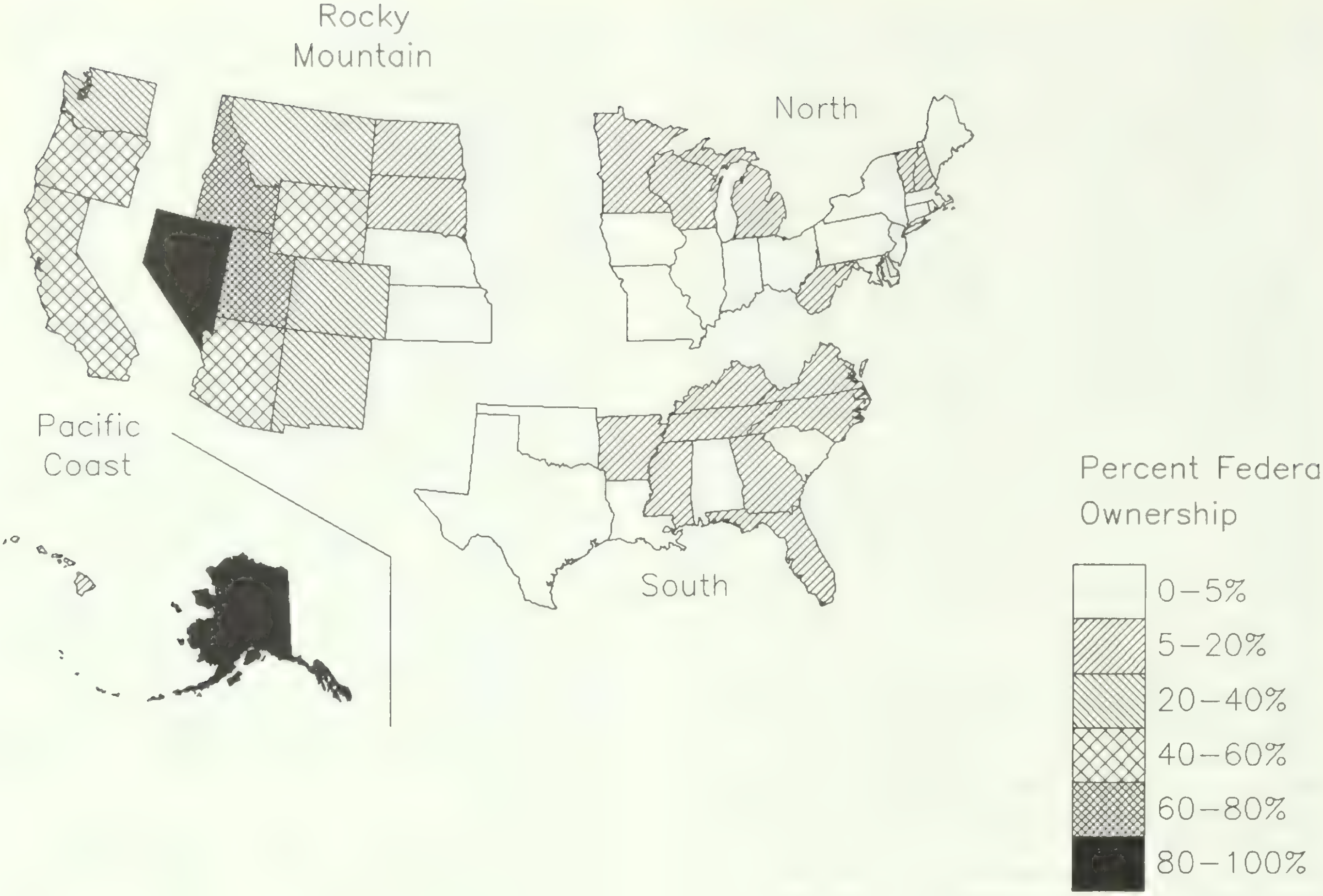
The following discussion documents the recent history of wildlife and fish on public lands in general, and specifically on Forest Service (FS) and Bureau of Land Management (BLM) lands. These two agencies are emphasized because they administer the majority of federal lands and because they are directed by legislation to monitor and manage wildlife and fish resources in a multiple resource context. Because public land distribution varies considerably across each assessment region (fig. 38), the recent trends in wildlife and fish resources on the agencies' lands differ accordingly.

The National Forest System (NFS) comprises 191 million acres on 156 national forests (186.4 million acres), 19 national grasslands (3.8 million acres), and a number of other land units associated with land-utilization projects, research and experimental areas, and purchase units. These lands are primarily in the West, which contains 87% of NFS lands. Apart from comprising a much smaller proportion of the land base, eastern NFS lands are further distinguished from those in the West by the significant amount of private inholdings that often occur within a national forest's promulgated boundary—a characteristic requiring careful consideration in managing natural resources, particularly mobile resources such as wildlife and fish.

The NFS is one of the most valuable public land networks for the nation's wildlife and fish resources (Barton and Fosburgh 1986). This value is reflected in habitat diversity, the number and variety of wildlife and fish species, and the number of recreationists that use the NFS. National forests contain approximately 128,000 miles of streams, 2.2 million acres of lakes, and more than half the nation's big game habitat. These aquatic and terrestrial habitats are used by over 3,000 species of wildlife and fish, and support 41% of the recreational use that occurs on all federal lands (Barton and Fosburgh 1986), of which 14% is devoted to wildlife and fish-related recreation including birdwatching, fishing, and hunting (USDA Forest Service 1985b).

The BLM has exclusive management jurisdiction on approximately 334 million acres (USDI Bureau of Land Management 1986). The BLM manages 46% of all federal lands—more than any other federal agency. These lands are primarily distributed west of the Mississippi River with only 0.7% of the land administered by the BLM occurring in the East.

Within its boundaries, the BLM manages a variety of ecosystems including Alaskan tundra, old-growth forest of the Pacific Northwest, and the deserts of the Southwest. Associated with these ecosystems is a variety of wildlife and fish species that are enjoyed by consumptive and nonconsumptive users. These lands not only provide essential habitat for game species, they are also critical to the survival of rare and endangered wildlife and fish. The BLM has management responsibility for over 80% of the desert bighorn sheep habitat as well as 130 plant and animal species listed as threatened and endangered (USDI Bureau of Land Management 1988).



Source: The Conservation Foundation (1984)

Figure 38.—Federal lands as percentage of total area, by state, 1980.

The lands administered by the FS and BLM constitute a vast land area that supports many renewable natural resources. Under a multiple resource management philosophy, the current status of and recent trends in wildlife and fish resources on FS and BLM lands have been, in general, more auspicious than those observed on private lands.

Wildlife and Fish Habitat on Public Lands

Forestland Habitats

Most forestland is privately owned. Nearly 71% of the total forestland in the United States was in nonfederal ownership in 1987 (Bones in press). Of the forestland under federal management (29%), the majority is managed by the FS (67%); the BLM manages an additional 13%; and the remaining 20% falls under the jurisdiction of the Fish and Wildlife Service, the National Park Service, or the Department of Defense. Most federal forestland is found in the Rocky Mountain and Pacific Coast regions, with federal lands in the East only constituting about 9% of the regional forestland area.

One indication of forest habitat status on public lands is the trend in timber removals. The annual removals of growing stock indicate that since 1962 removal rates across all ownerships have increased (table 22). Proportionately, the increase has been the greatest on forest industry lands. Comparison of average removals for the 1962–1970 and the 1976–1986 periods indicates that timber removals have increased 43% on forest industry lands, 36% on other public lands, 12% on other private lands, and 3% on NFS lands.

The regional pattern in timber harvests varies in relation to the predominance of public land within each region. The South and Pacific Coast regions supply the majority of the harvested timber volume. In the South the majority (over 90% in 1986) of the harvested volume comes from private lands, whereas in the Pacific Coast 42% comes from public lands. Of these two major timber producing regions, the South has had the most significant increases in timber removals since 1962 (table 22).

The timber harvesting that has occurred on national forests, and public lands in general, required an extensive network of roads. Road construction has resulted in a number of outcomes including: (1) increased access

Table 22.—Trends in timber removals by ownership and assessment region (1962–1987).

Region	Year	NFS	Other public	Forest industry	Other private
			Million cubic feet		
All regions	1962	1,873	723	2,958	6,406
	1970	2,322	966	3,765	7,041
	1976	2,121	1,077	4,229	6,802
	1987	2,209	1,216	5,380	8,235
North[1]	1962	84	137	213	1,643
	1970	100	173	323	1,876
	1976	124	184	406	1,945
	[4]1987	119	155	582	1,895
South[2]	1962	186	130	1,133	4,075
	1970	272	184	1,497	4,548
	1976	286	213	1,791	4,279
	[5]1987	314	291	2,425	5,668
Rocky Mountain[3]	1962	414	86	130	111
	1970	527	86	186	94
	1976	465	93	177	110
	1987	455	74	161	139
Pacific Coast	1962	1,188	369	1,481	577
	1970	1,423	523	1,759	523
	1976	1,244	586	1,855	468
	1987	1,321	696	2,212	534

[1]*Includes ND, SD (east), NE, KS, and KY.*
[2]*Does not include KY.*
[3]*Does not include ND, SD (east), NE, KS.*
[4]*Does not include KY.*
[5]*Includes KY.*
Source: Haynes (in press), USDA Forest Service (1982).

for fire, insect, and disease protection; (2) increased access for wildlife and fish recreation; (3) potential increased disturbance of sensitive wildlife species including elk and grizzly bears; and (4) increased stream sedimentation resulting in degraded fish habitat (Council on Environmental Quality 1985, Fosburgh 1985b).

In addition to road development impacts, other forest habitat issues are emerging about public lands. Old-growth habitats are becoming increasingly rare, particularly on private lands. In 1977, more than half of the remaining old-growth in the Pacific Coast occurred on national forests; most of the old-growth in the Rocky Mountains occurs on NFS lands; and in the South, current trends indicate that much of the old-growth pine forests will only be found on national forests or other public lands (Lennartz et al. 1983).

With increasing management intensity on private timberlands, public forestlands will become increasingly unique when compared to private ownerships. This is of primary concern in the East for two reasons: (1) national forests could become isolated habitat islands which could threaten the maintenance of biological diversity (Harris 1984, Lennartz et al. 1983, Norse et al. 1986); and (2) public preferences are modifying the objectives for managing national forests to include increased consideration of the unique environments found there.

Rangeland Habitats

The majority (64.1%) of the nation's rangeland acres are in private ownership (Bones in press). Of the 276 million acres of rangeland in public ownerships, the BLM and FS administer 54% and 15%, respectively.

The condition of federally owned rangelands is difficult to evaluate for wildlife and fish resources. If we assume that range in good condition for certain domestic species will also be in good condition for similar wildlife species (Wagner 1978), then rangeland habitats on BLM and NFS lands appear to be improving (Joyce in press). Reduced use and improved management have contributed to range rehabilitation, although the recovery appears slow on BLM lands due to the long history of uncontrolled free range use and the longer vegetation recovery periods characteristic of arid climates (Council on Environmental Quality 1985).

Public lands only provide about 7% of the total grazed forages consumed by livestock (Joyce in press). Recent trends in grazing use of federal rangelands, as measured by animal unit months (AUM's), indicate that total grazing use of NFS and BLM lands declined through the mid-1970's (table 23). From 1980 to 1985, however, there was a slight (about 6%) increase in the grazing use of NFS and BLM lands—despite a nationwide decline in cattle herd size across all ownerships. This short-term trend

likely is due to a redistribution of the industry from East to West where public lands are the predominant ownership (Joyce in press).

On NFS lands, grazing use declined approximately 4% from 1965 to 1975, after which use increased to levels exceeding those reported in 1965 (table 23). The low use level reported for 1975 reflects, in part, the state of the cattle industry at a time when much of the nation's livestock went to market and grazing declined. Trends in NFS grazing use by assessment region are similar to the nationwide trend with all regions showing gains in the last 5 years.

Bureau of Land Management rangelands have witnessed a general reduction in grazing use. During the 1970–1980 decade, BLM lands experienced a total decline in grazing use of 21% (table 23). The majority of the decline occurred in the Rocky Mountain region with use in the Pacific Coast remaining relatively constant. Subsequent grazing use on BLM lands (1980–1985) increased 9%.

The overall impact of these grazing trends on rangeland habitats for wildlife and fish is difficult to determine. Obviously, livestock grazing can cause numerous conflicts with wildlife and fish resources; however, the extent of the conflicts cannot be easily quantified.

One of the most important wildlife and fish issues related to rangeland grazing concerns the impacts of livestock on riparian areas. Barton and Fosburgh (1986) characterize cattle damage to riparian zones on public lands as the most serious conflict between livestock and wildlife and fish. Heavy use of riparian areas by livestock results in a direct and significant impact on both terrestrial and aquatic habitats (Ohmart and Anderson 1986), and these habitats are particularly important in the arid environments that characterize much of the western rangelands. Nearly 76% of the breeding birds in the Southwest depend on water-related habitats (Johnson et al. 1977); in Oregon's southeastern Great Basin country, nearly 80% of terrestrial wildlife species depend on riparian zones or use these areas more than other habitats (Thomas et al. 1979); and 40% of the vertebrate wildlife species in Colorado associate with riparian areas which comprise only 3% of the land base (Melton et al. 1984). Besides the importance of riparian areas to livestock and wildlife, riparian areas are also valued for their recreational opportunities and are prime sites for road construction (Thomas et al. 1979).

The concern for riparian management on NFS and BLM lands is heightened when one considers only 3 million acres of riparian habitat are managed by these agencies (Prouty 1987). The varied demands concentrated on riparian areas make this habitat type a focal point for resource conflict (Platts 1979). Unfortunately, inventory information on riparian habitats is inadequate to evaluate recent trends in the condition of this important habitat type.

Wetlands

Nearly 74% of the remaining wetland habitats are privately owned, leaving about 25% under either federal or state ownership and 2% under the jurisdiction of local governments (USDI Fish and Wildlife Service n.d.a) With increasing human populations, and the proximity of population centers to coastal wetlands, the pressure to develop private wetlands will remain intense (Tiner 1984). As private wetland habitat continues to be lost, the importance and value attributed to those acres protected under federal and state ownerships will continue to escalate.

Within the federal ownership category, 40% of the lands classified as wetlands are managed by the Fish and Wildlife Service (fig. 39). The FS has management responsibility for 23% and the National Park Service, BLM, Corps of Engineers, Bureau of Reclamation, and Air Force manage the remaining 37%.

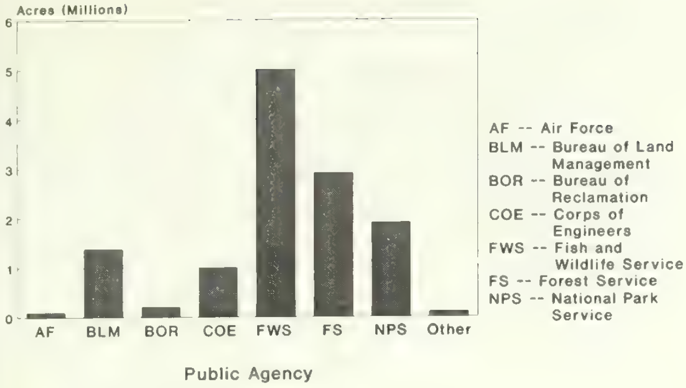
No standard national inventory permits an assessment of wetland trends in the FS. However, the Public Land Statistics published by the BLM do report wetland acreage. The number of wetland acres under the BLM's jurisdiction have declined since 1979 (table 24). This trend is not a reflection of actual degradation or destruction of wetland habitats but a reflection of recent Alaskan land transfers from the BLM to the State and Native Americans. Alaska accounted for 97% of the total BLM wetland acres in 1986.

The trends in BLM wetlands by assessment region are more indicative of the management emphasis that wetland types are receiving. In the Pacific Coast region, the dynamics are again dominated by the land transfer

Table 23.—Trends in grazing use on NFS and BLM lands.

Year	Total		North	South	Rocky Mountain		Pacific Coast	
	NFS	BLM[1]	NFS	NFS	NFS	BLM[1]	NFS	BLM[1]
	Thousand AUM's							
1965	9,339		108	184	8,004		1,043	
1970	9,284	13,039	40	354	7,910	11,651	980	1,388
1975	8,971	11,935	54	316	7,492	10,550	1,109	1,386
1980	9,757	10,308	67	225	8,202	8,929	1,263	1,380
1985	10,124	11,218	78	248	8,431	9,812	1,366	1,406

[1]*Multiply by 1.2 to be comparable to NFS, see Joyce (in press) for explanation.*
Source: Joyce (in press).



Source: USDI, Fish and Wildlife Service [n.d.]a

Figure 39.—Distribution of federally-owned wetland habitats.

Table 24.—Trends in wetland acres on lands administered by the BLM.

Year	National	Pacific Coast	Rocky Mountain	Eastern
		Thousand acres		
1979	46,951	46,797	154	
1980	48,960	46,794	151	35
1981	23,189	23,018	171	33
1982	27,474	27,289	185	35
1983	17,235	16,043	192	35
1984	16,246	16,043	203	35
1985	16,248	16,041	207	35
1986	16,248	16,041	207	37

Source: USDI Bureau of Land Management (1981–1987).

pattern in Alaska. This masks the general increase in BLM wetland habitat reported in California, Washington, and Oregon. Similar increasing trends in wetland area are also observed in the Rocky Mountain region where wetland acres have increased by over 35% since 1979. These increases are attributed to a number of factors including more intensive wetland improvement programs, a wet weather cycle during 1983–1985, and more intensive inventories and more precise definitions that have resulted in more acres being classified as wetland.

Wildlife and Fish Populations on Public Lands

Big Game and Other Large Mammals

Wildlife population statistics on public lands are compiled in cooperation with state wildlife agencies. Historical trends are published by the FS and BLM in their annual reports concerning wildlife and fish management on lands under their jurisdiction (USDA Forest Service 1965–1977, 1978–1985; USDI Bureau of Land Management 1966–1988). The populations reported by these two agencies are not mutually exclusive estimates and therefore cannot be added to estimate total populations on public lands. The migratory habits of many large mammal species can result in the use of FS and BLM lands at different times of the year. In addition, the lands managed by these agencies are occasionally "checkerboarded" with private lands preventing a definitive censusing.

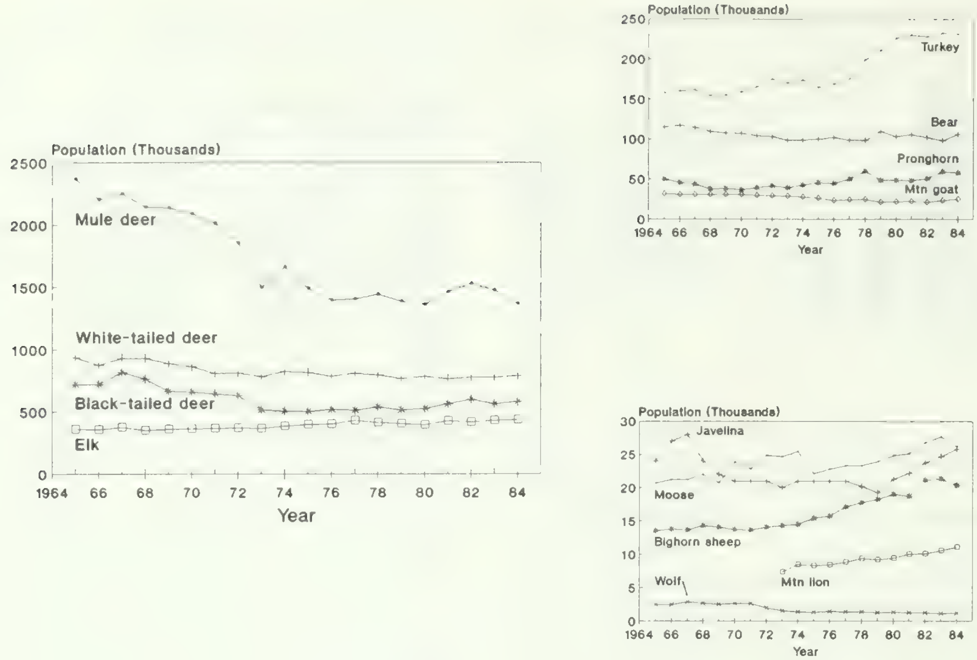
Big game populations in the NFS have, in general, remained stable or increased over the recent historical period of this report (fig. 40). The mule deer, including the black-tailed deer subspecies, is an exception. It declined during the late 1960's through the mid-1970's. This decline was range-wide and not specific to NFS lands. No single factor has been identified as being responsible for the decline (Connolly 1981). The only other large mammal that has shown a significant decline is the gray wolf. Wolf numbers have declined by 50% since the 1970's. Factors contributing to this decline include forest successional changes in the north-central portion of the U.S. that support less prey (The Conservation Foundation 1984) and wolf reduction efforts in Alaska aimed at increasing ungulate populations for sport and subsistence use (Peterson 1986). The most notable increases in big game abundance have occurred with wild turkey, moose, elk, bighorn sheep, and mountain lion.

Within assessment regions, population trends vary from the nationwide trends. In the North (appendix C, table C-1), bear and turkey populations have remained fairly stable, while moose populations have increased by nearly 70% since 1965. White-tailed deer declined through the early 1970's, after which numbers appear to have stabilized at about 300,000 animals. The decline in northern deer abundance may be related, in part, to declining forestland acreage in the early successional stages that provide higher carrying capacity.

Southern big game abundance trends have either been increasing or stable since 1965 (appendix C, table C-2). White-tailed deer numbers have remained between 250,000 to 300,000 while black bears have fluctuated around 3,000 animals. Wild (feral) pig populations have gradually increased in the last 20 years; in some areas, populations have increased to levels where competition with native fauna and damage to flora is a concern. Wild turkeys are a success story in the South. Numbering around 40,000 birds in 1965, turkeys increased threefold by 1984.

Big game and other large mammal species inhabiting the Rocky Mountains have had varying population trends (appendix C, table C-3). While moose, pronghorn, elk, mountain lion, and bighorn sheep have all gradually increased over the last 20 years, black bear and collared peccary populations have remained relatively stable. Species that have tended to decline include deer, turkey, mountain goat, and woodland caribou although it now appears that turkey and deer numbers are recovering.

In the Pacific Coast region, several species have increased significantly. Wild turkey and pronghorn populations have increased by 200% and 79%, respectively (appendix C, table C-4). Declining species include the gray wolf, deer, mountain goat, and bear.



Source: USDA, Forest Service (1965-1977, 1978-1985)

Figure 40.—Trends in big game populations on NFS lands.

Trends in big game populations on BLM lands generally are consistent with the trends observed on NFS lands. However, for Alaskan big game species, the trends are heavily influenced by the conveyance of land to the State and Native Americans. Of the species that were minimally affected by the land transfer, pronghorn and elk have shown increasing numbers while deer have declined (table 25). Of the Alaskan species, trends prior to and after the land transfer appear to be either stable or upward. The only exception to this pattern is with caribou, the population of which declined from the late 1960's through the early 1970's.

The eastern-states BLM office reported stable big game trends since 1980. Because of small BLM acreage in the east, these lands do not make a significant contribution to national big game production. In 1985, 100 moose, 1,200 deer, and 100 black bears used eastern BLM lands during part of the year.

In the Rocky Mountain region, the BLM showed significant increases for all species except deer (table 26). The most significant gains over the 1966–1985 period were observed with bear (378%), elk (227%), and moose (135%) populations. Deer numbers have declined by 27%.

Trends reported for the Pacific Coast region are influenced by the conveyance of BLM land in Alaska making interpretation of long-term trends difficult. Qualitative evaluations are possible by examining trends prior to and after the mid-1970's estimates. Deer and caribou were the only species showing downward trends (table 27). The deer decline is attributed to a drop in mule deer abundance in California, Oregon, and Washington. A presumed cause for the caribou decline is heavy harvest of adults and high calf predation from gray wolves and grizzly bears (Bergerud 1978).

Threatened and Endangered Species

Since federal land managing agencies have a legal responsibility to improve the status of threatened and endangered species, the association that exists between endangered species and federally administered habitat is important to understand. The association is due, in part, to land management actions that have maintained or enhanced endangered species habitats to the point where public lands are frequently the only place where these species still exist. In addition, the criteria that were used to justify the acquisition or retention of federal land frequently meant that public lands were unique with respect to animal species occurrence. For example, the Fish and Wildlife Service actively acquires land as a means of protecting threatened and endangered species as authorized under the Land and Water Conservation Fund, and the National Park Service has continually acquired some of the most unique lands in the United States. As a result, a high proportion of endangered species inhabit public lands.

The FS's threatened and endangered species program includes habitat management for endangered, threatened, proposed, and candidate (category 1 or category 2) species. The ''proposed'' category includes those species officially proposed for listing by the Fish and Wildlife Service or the National Marine Fisheries Service. ''Candidate'' species comprises taxa for which the Fish and Wildlife Service currently has substantial biological information to support a proposal to list the species

Table 25.—Trends in selected big game populations on BLM lands.

Year	Moose	Pronghorn	Elk	Deer	Sheep	Caribou	Bear
				Thousands			
1966	91	175	42	1,689	45	600	21
1970	101	183	67	1,462	44	600	25
1975	152	191	96	1,499	41	450	74
1980	88	241	101	1,260	45	250	37
1985	89	266	130	1,209	21	260	38

Source: USDI Bureau of Land Management (1966, 1970, 1975, 1981, 1986).

Table 26.—Trends in selected big game populations on BLM lands in the Rocky Mountain Region.

Year	Moose	Pronghorn	Elk	Deer	Sheep	Bear
			Thousands			
1966	1	162	35	1,176	7	1
1970	1	168	61	945	7	2
1975	2	147	86	968	9	2
1980	3	223	96	843	9	3
1985	3	246	114	855	13	4

Source: USDI Bureau of Land Management (1966, 1970, 1975, 1981, 1986).

Table 27.—Trends in selected big game populations on BLM lands in the Pacific Coast.

Year	Moose	Pronghorn	Elk	Deer	Sheep	Caribou	Bear
				Thousands			
1966	90	13	8	513	38	600	20
1970	100	14	6	517	38	600	23
1975	150	14	11	530	32	450	72
1980	85	17	13	414	36	250	34
1985	85	20	16	353	8	260	35

Source: USDI Bureau of Land Management (1966, 1970, 1975, 1981, 1986).

as endangered or threatened (category 1), or taxa for which current information indicates that listing species may be appropriate but conclusive biological data are not available to support the development of proposed rules (category 2).

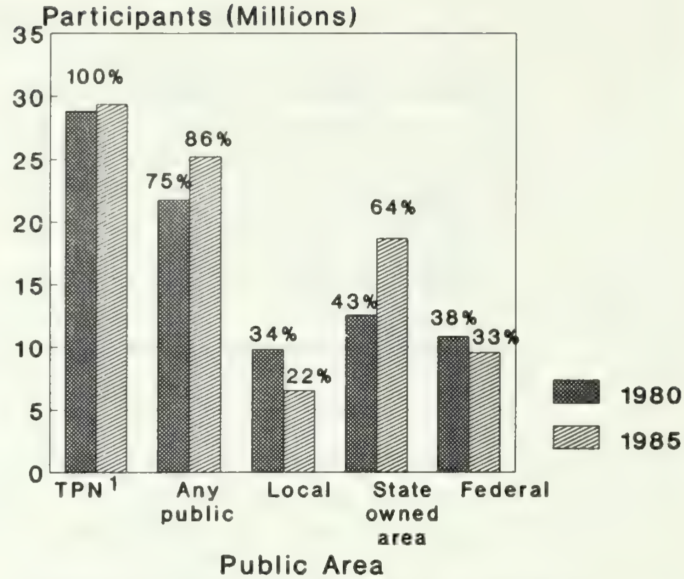
Currently, 109 endangered species, 42 threatened species, 4 species either endangered or threatened depending on location (e.g., grizzly bear), 9 proposed species, plus an additional 90 category 1 species and 737 category 2 species occur on FS lands (Raml, pers. comm., 1988). Consequently, the FS manages habitat that directly affects approximately 30% of the U.S. plant and animal species which have been listed by the Fish and Wildlife Service. The Southern, Southwestern, and Eastern Forest Service Regions had the greatest number of proposed, threatened, or endangered species; the Northern and Alaska Regions had the least (Raml, pers. comm., 1988). The number of listed species occurring on NFS lands is expected to increase as new species are listed and as new information on species distributions becomes available.

The BLM currently has responsibility for habitat used by 82 threatened and endangered animal species, of which 77 have approved recovery plans (USDI Bureau of Land Management 1988). The largest species concentration occurs in Nevada, with 21 threatened or endangered animal species occurring on BLM lands (table 28). BLM personnel have also estimated that they have land management responsibility for approximately 6.5 million acres of terrestrial and 1,850 miles of aquatic habitat used by threatened and endangered species. In addition to officially listed species, the BLM also provides habitat for 870 candidate species, some 620 of which are plants (see Joyce in press).

Table 28.—Number of threatened and endangered species and habitat occurring on BLM lands by state.

State	Animal species	Habitat acres (thousands)	Aquatic habitat miles
Alaska	5	100	
Arizona	17	454	304
California	19	350	6
Colorado	8	938	200
Idaho	6	81	302
Montana	8	400	250
Nevada	21	36	339
New Mexico	7	50	10
Oregon	7	97	12
Utah	13	2,160	446
Wyoming	5	1,846	
Eastern U.S.	13	50	

Source: USDI Bureau of Land Management (1988).



[1]Total primary nonresidential participation on all ownerships

NOTE.—Percentages reflect the proportion of total primary nonresidential participation for a given year. Percentages across land ownerships will not sum to 100 since persons may participate in several ownership categories.

Source: USDI. Fish and Wildlife Service, and USDC, Bureau of Census (1982); USDI, Fish and Wildlife Service (1988a)

Figure 41.—Participation on public areas by primary nonresidential participants.

Recreational Use of Wildlife and Fish on Public Lands

Proportionate Use Patterns of Public Lands

Ownership patterns in wildlife-related recreation, measured as the proportion participants or days spent recreating within various land ownerships, were obtained from the Fish and Wildlife Service's National Surveys of Fishing, Hunting, and Wildlife-Associated Recreation. These surveys represent the only standard inventory of users that permits a national and regional comparison of where hunters and nonconsumptive recreationists chose to participate with respect to land ownership categories. These surveys have been conducted every 5 years since 1965; however, because of changes in survey design, historical trends are difficult to interpret. As opposed to earlier years, the 1980 and 1985 surveys were similar enough in their reporting of ownership use pattern to permit an evaluation of recent trends in public land use by the outdoor recreating public.

Nonconsumptive wildlife related recreation on public lands.—Within the nonconsumptive-use categories defined by the Fish and Wildlife Service, only primary nonresidential recreational participation was described in terms of land ownership. Results of the 1980 (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982) and 1985 (USDI Fish and Wildlife Service 1988b) surveys indicate that public land areas are critical to primary nonresidential nonconsumptive recreation, and they are becoming more important (fig. 41). In 1980, 75% of the total nonconsumptive users participated on public lands, and that figure increased to 86% in 1985. The majority of the increase is associated with state-owned areas which witnessed a 20% increase in proportional participation. Participation declined significantly on local areas and declined slightly on federal lands.

Hunting on public lands.—The trends in proportionate hunting use by ownerships showed minor shifts during the period of 1980 to 1985 (table 30). The days spent hunting on public lands for all types of hunting activities declined by 3.4%. This was the result of a significant drop in the days spent on the "other" public land category. The proportionate number of days spent on federal and state-owned areas actually increased by 2% between 1980 and 1985. The increased use of federal and state lands is explained by less habitat being available from private land due to more intensive land use and reduced accessibility.

The patterns observed for all hunting activities are generally maintained across each hunting type with the exception of big game. The proportionate number of days that big game hunters spent on public lands declined to a much greater degree than was observed for small game or migratory bird hunting. In addition, the proportion of days spent big game hunting on federal lands declined slightly between 1980 and 1985—the only type of hunting where this was observed.

Trends in the Number of Participants on Public Lands

Proportionate use, as discussed above, only provides information on the relative importance of different land ownerships to hunting and nonconsumptive activities. The results of that analysis showed that public lands, in general, are receiving a greater share of the nonconsumptive and consumptive wildlife-related recreation. However, these figures do not provide information on the magnitude of use on these ownerships; such data were obtained from annual reports published by the FS.

Nonconsumptive recreation.—Within the NFS, statistics on nonconsumptive activities (recorded as total nature study) were not collected until 1980. Since 1980,

Table 29.—Regional distribution of primary nonresidential participation on public lands in 1980.

Region of residence	Total primary nonresidential participants	Any public area		Local or regional park or natural area		State-owned area		National wildlife refuge		Other federal area	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
	Numbers in thousands										
National	28,822	21,731	75.4	9,820	34.1	12,545	43.5	4,561	15.8	6,283	21.8
North[1]	14,867	11,049	74.3	5,262	35.4	6,912	46.5	2,144	14.4	1,802	12.2
South[2]	6,754	4,604	68.2	1,791	26.5	2,414	35.7	966	14.3	1,281	19.0
Rocky Mountain[3]	2,125	1,725	81.2	577	27.2	735	34.6	264	12.4	970	45.7
Pacific Coast	5,076	4,353	85.7	2,192	43.2	2,484	48.9	1,068	21.0	2,228	43.9

[1]*Includes the states of ND, SD, KS, and NE and excludes MD, WV and DE.*
[2]*Includes the states of MD, WV, and DE.*
[3]*Excludes the states of ND, SD, KS and NE.*
NOTE: Detail does not add to total because of multiple responses.
Source: USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

Table 30.—Percentage of total days spent hunting on public land by type of hunting and ownership.

	1980				1985			
	All hunting	Big game	Small game	Migra. birds	All hunting	Big game	Small game	Migra. birds
	Percent							
All Public	31.6	40.7	25.9	28.7	28.6	34.2	22.9	28.4
Federal	9.3	15.4	5.9	6.0	10.4	15.1	6.3	8.3
State	10.4	13.2	8.8	10.1	11.6	13.2	10.1	11.6
Other[1]	11.9	12.0	11.1	12.5	6.6	5.9	6.5	8.5

[1]*Other public land includes locally managed areas and unclassified public land use.*
Source: USDI Fish and Wildlife Service (1988b); USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

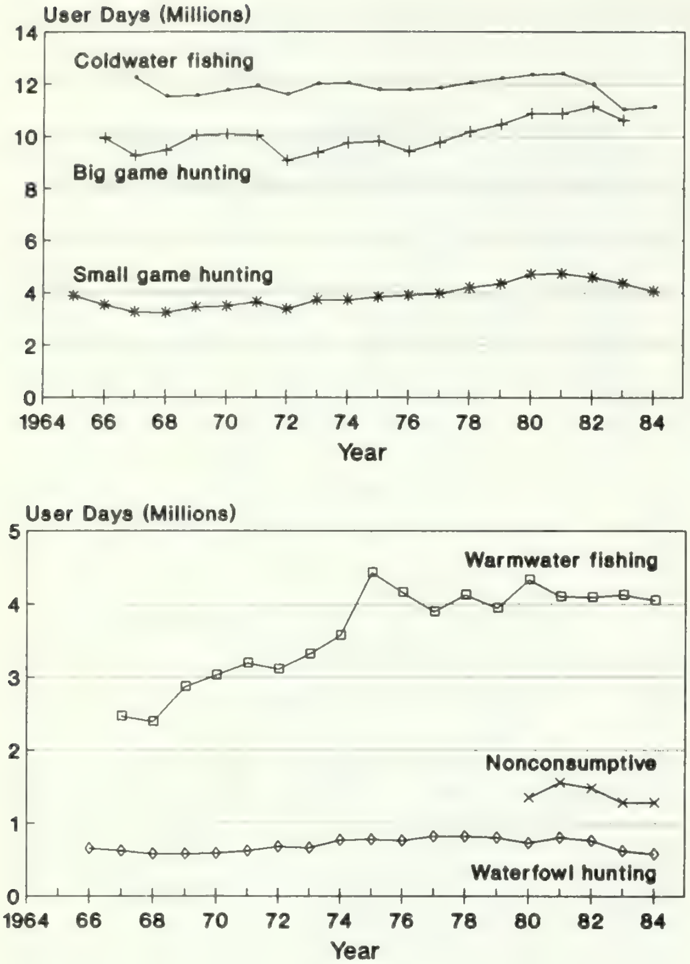
total nonconsumptive user-days on NFS lands peaked in 1981 at 1.55 million user-days and declined to approximately 1.27 million user-days in 1984 (fig. 42). Although this trend is surprising given increased public interest in nonconsumptive recreational activities, participation in primary nonresidential nonconsumptive activities may be leveling off. Over the period from 1980 to 1985, the Fish and Wildlife Service noted a general decline in the proportion of the population participating in primary nonresidential nonconsumptive activities and actual declines in the number of participants in some regions of the country (USDI, Fish and Wildlife Service 1988b; USDI Fish and Wildlife Service, and USDC Bureau of Census 1982).

Regional trends in nonconsumptive use on NFS lands, in general, follow the national trends within this ownership (appendix C, table C-5). Nonconsumptive user-days declined in every region from 1980 through 1984 except in the South. This regional pattern is consistent with the regional trends across all land ownerships. The South experienced the most significant gains in primary nonresidential participants while participation declined in the North and Pacific Coast regions (see table 13).

Migratory game bird hunting.—The only available statistics on trends in migratory bird use were for waterfowl hunting and therefore do not include the webless migratory species. Waterfowl use on FS lands peaked in 1978 at approximately 800,000 user-days. By 1984, use was 25% below peak levels (fig. 42).

Although the waterfowl use pattern on NFS lands within each assessment region is consistent with that observed on all land (appendix C, table C-6), the magnitude of the decline varies greatly by region. The Pacific Coast region has had the greatest decline from peak use (approximately 50%) while use has remained relatively stable in the Rocky Mountains (10% decline from peak period). The trend in waterfowl use on eastern national forests has ranged from a 32% decline in the North to an 18% decline in the South.

The downward trend in waterfowl use on FS lands is not specific to these lands as waterfowl use has consistently declined across all ownerships. The decline is likely a function of many interacting factors including declining waterfowl populations, regulations, and changes in recreational preferences.



Source: USDA, Forest Service (1965-1977, 1978-1985)

Figure 42.—Trends in wildlife-related recreation user-days on NFS lands.

Big game hunting.—The number of user-days that the recreating public has devoted to big game hunting on national forests has been increasing nationwide (fig. 42). From 1966 through 1977, big game user-days fluctuated around 9.5 million, after which a gradual increase was observed, peaking in 1983 at 11.1 million user-days. This trend is generally maintained within each assessment region although the magnitude of changes varies by region (appendix C, table C-7). The North has witnessed over a 55% increase in big game hunting use since the early 1970's. Big game hunting use in the South has increased consistently since 1967 and appears to be related to the previously noted deer and turkey population increases. Trends in big game hunting use within the Rocky Mountain region lagged a few years behind the dynamics of mule deer populations. The decline in deer numbers during the early 1970's is followed by declining use in the mid to late 1970's. Since 1978, the number of big game user-days has increased to record levels in the Rocky Mountains. Pacific Coast big game hunting use on NFS lands has remained relatively stable over the last 20 years, fluctuating around 2.9 million user-days.

Although the number of days spent pursuing big game on FS lands has increased or remained stable, the importance of each region in terms of its relative contribution to the national total is shifting. The West has always accounted for the majority of big game use on FS lands (approximately 70% of the national total). However, between the 1966–1968 and 1982–1984 periods, the average contribution of each region to the national total showed that the South has had the greatest percentage gain (16.8% to 19.2%), followed by the Rocky Mountains (40.4% to 42.2%) and North (10.8% to 11.8%). The Pacific Coast's relative contribution to the total number of big game user-days has declined by over 5% between the two time periods.

Small game hunting.—National forest personnel have reported the number of small game mammal and upland game bird user-days as a part of the annual wildlife report from 1965 through 1984. The trend for combined small game mammal and upland game bird users was upward for the first 15 years followed by a noticeable decline (fig. 42). In 1984, the South accounted for the greatest proportion of national forest small game use (42%); the North and Rocky Mountains accounted for a similar proportion of small game user-days (24% and 22%, respectively); and the Pacific Region had the smallest proportion of small game use at 12% (appendix C, table C-8). Small game species occupying national forests are generally not associated with agricultural lands. Therefore, small game recreational use on NFS lands has not been influenced by the general national decline in agriculture-associated small game populations.

Fishing.—Following a decline of 4 million fishing user-days in the late 1960's, fishing has steadily increased on national forests through 1980. The level of coldwater angling use on national forests was consistent at nearly 12 million user-days between 1967 and 1981, after which use dropped to about 11 million by 1984 (fig. 42). Warmwater fishing user-days nearly doubled between 1967 and 1975, after which numbers stabilized at about 4 million user-days (fig. 42).

Important regional differences exist in the distribution of angling use on national forests (appendix C, table C-9). In the North, fishing has stabilized around 2 million fishing user-days. Warmwater fishing participation increased from less than 900,000 user-days in 1967 to about 1.4 million by 1984. Coldwater fishing has maintained a relatively stable level of use at about 650,000 user-days.

The amount of fishing use on Southern national forests increased from less than 2 million to about 3 million user-days over the 1965–1984 reporting period. These trends are influenced by the amount of warmwater fishing which makes up over two-thirds of the fishing use in the region.

In the Rocky Mountain region, coldwater fishing accounts for nearly 95% of the total number of recreational fishing days on NFS lands. After averaging about 5 million user-days through 1975, coldwater fishing use increased to 6 million user-days by the early 1980's. No trend is apparent in warmwater fishing with use fluctuating around 300,000 user-days.

The total number of fish user-days on Pacific Coast national forests has fluctuated in the recent past. However, the general trend is one of declining use, particularly over the 5-year period from 1979 to 1984. As in the Rocky Mountains, coldwater fishing is dominant, accounting for over 90% of the total fishing use. The decline in coldwater fishing participation is probably a function of many factors including declining anadromous fish numbers during the late 1970's and early 1980's and regulations (Lee, pers. comm., 1987).

Harvests of Wildlife and Fish on Public Lands

Big Game and Other Large Mammal Harvests

Harvest statistics for big game species (including gray wolf) on public lands were available for FS lands only. National trends in total big game harvest can be explained, in part, by trends in animal populations and users. Regression analysis showed that 88% of historical harvest variations is explained by changes in big game populations and hunter effort (as measured by user-days). Other factors that influence observed harvest levels include hunting season regulations and weather.

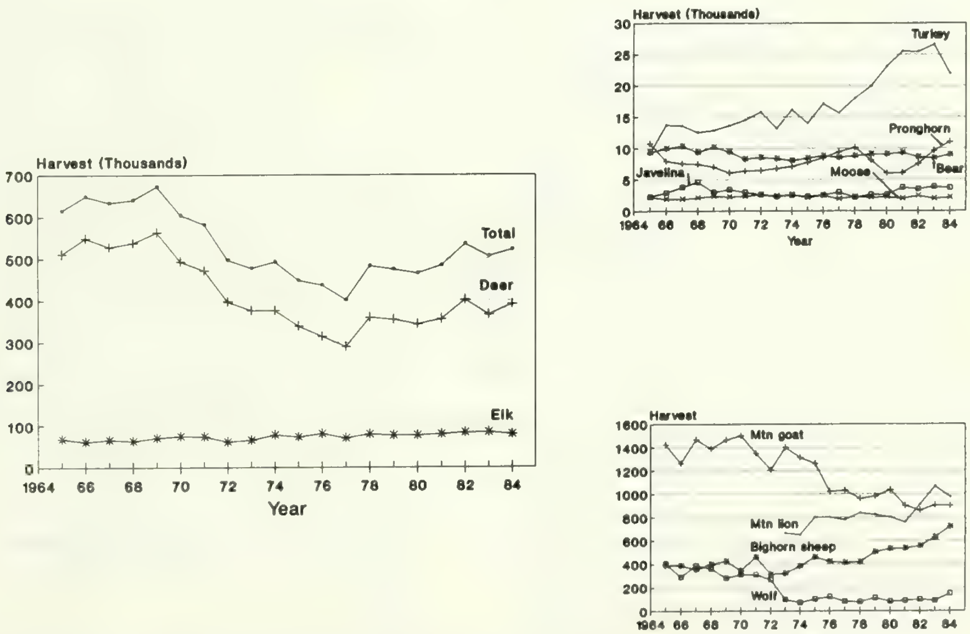
Total big game harvests on FS lands declined from 1965 through 1977, followed by a gradual increase through 1984. This observed trend is dominated by the historical harvest of deer which account for approximately 75% of the total number of big game animals harvested (fig. 43). Harvests of elk, turkey, mountain lion, and bighorn sheep have also increased while mountain goat and wolf harvests have declined.

In the Northern region, both turkey and black bear harvests increased on FS lands. Deer harvests reached a record low in the early 1970's, after which harvest increased to levels approaching those observed in the mid-1960's (appendix C, table C-10).

All species of big game showed increased harvests on Southern national forests. Turkeys showed a 350% increase in harvest since 1965 while deer and black bear harvests increased by 145% and 95%, respectively (appendix C, table C-11).

Rocky Mountain big game harvest trends are variable owing to the diversity of big game species found on national forests in this region (appendix C, table C-12). Deer have accounted for the majority of the big game harvest in this region. During the mid-1960's, deer accounted for at least 80% of the total big game harvest. During periods of lower populations (mid to late 1970's), deer harvests accounted for only 60% of the big game total. Species that have shown consistent increases in harvest include elk, pronghorn, bighorn sheep, and mountain lion. The only species with a consistently declining harvest trend is mountain goat.

Big game harvests from FS lands in the Pacific Coast Region appear more variable than the other regions (appendix C, table C-13). Fall weather patterns, particularly in Alaska, have a significant influence on observed big game harvests of moose, mountain goat, sheep, and caribou. Species showing consistently increasing harvests are those found on national forests in California, Oregon, and Washington and include pronghorn and wild turkey. Regional wolf and bear harvests have declined by 50% and 25%, respectively.



Source: USDA, Forest Service (1965-1977, 1978-1985)

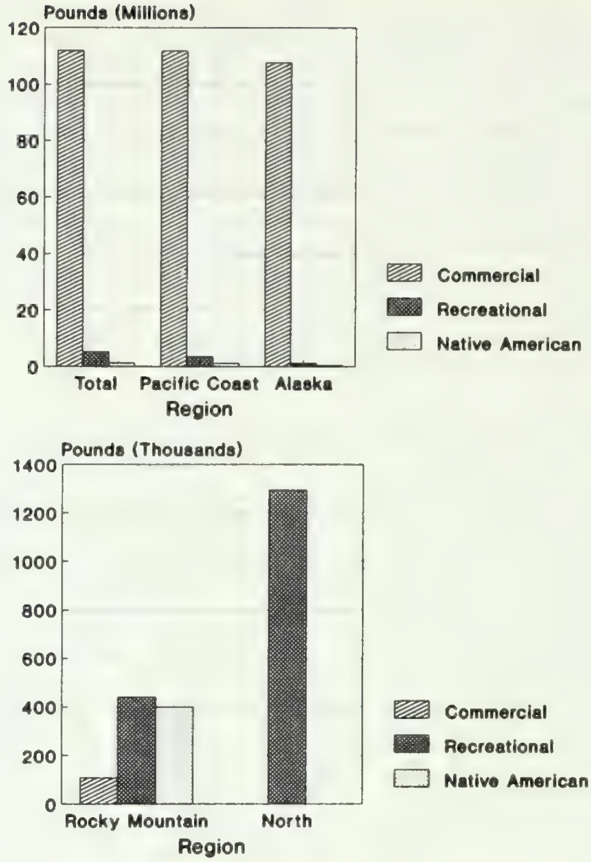
Figure 43.—Trends in harvest of selected big game species on NFS lands.

Fish Harvests

The FS and BLM have annually reported the harvest of anadromous salmon and steelhead but not the harvest of other fish species. Anadromous fish harvests from FS and BLM lands are based on the estimated contribution that these lands make to the annual production of these species, rather than the harvest that actually occurs on NFS lands.

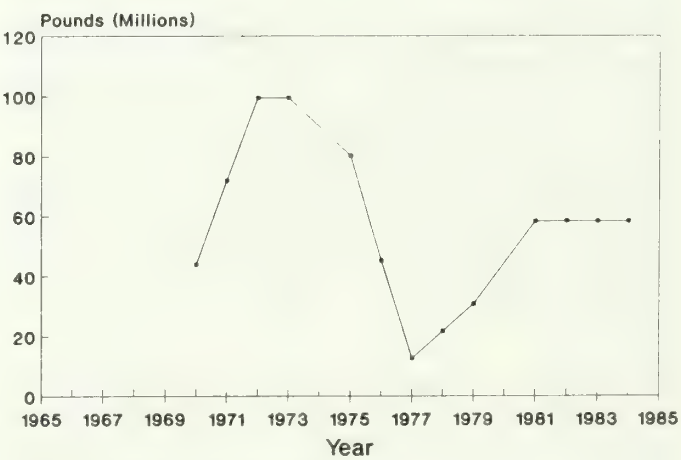
For national forests, information on fish harvests are categorized as commercial, recreational, and Native American. The largest segment of the harvest is taken by commercial fishing. The total salmon harvest for the nation was about 700 million pounds, of which 15% (112 million pounds) was attributable to the NFS (fig. 44). Considering the 5 million pounds of salmon and steelhead harvested by recreational users and 2 million pounds taken by Native Americans, national forest contributed nearly 120 million pounds of salmon and steelhead in 1984. The majority of the recreational (40%) and Native American (50%) harvest of salmon and steelhead occurs in the Pacific Coast region.

The trend in commercial fish harvested on BLM lands has been highly variable during the last 20 years. A high of 100 million pounds was harvested in 1972 and 1973 followed by a low of only 12 million pounds in 1977 (fig. 45). In recent years, the commercial harvest of anadromous fish produced on BLM lands has been around 60 million pounds.



Source: Dombeck (pers. comm. 1987)

Figure 44.—Salmon and steelhead harvested from national forest production.



Source: USDI, Bureau of Land Management (1970-1985)

Figure 45.—Trend in commercial fish harvest from BLM public land production.

Summary

Public lands constitute a vast area that supports many renewable natural resources of which wildlife and fish are an important component. The NFS together with the Bureau of Land Management are responsible for the management of 525 million acres of forest and rangeland ecosystems. As multiple-use land managing agencies, the FS and BLM give wildlife and fish prominent consideration in resource management activities. Consequently, forest and rangeland ecosystems on public lands provide habitat for a diversity of wildlife and fish species. However, indications are that important wildlife and fish habitat will be lost or diminished in quality unless wildlife and fish concerns continue to be acknowledged in future resource planning.

Within forest environments, important habitat issues on public lands are ultimately tied to trends in timber removals. Harvest of timber is dependent on roads, and recent construction trends have heightened concern for the potential impacts on species sensitive to human disturbance and increased sedimentation of stream habitats. Timber harvesting also alters the mix of forest successional stages. As demands for timber increases, old-growth forest environments are becoming increasingly rare on private lands, leaving public agencies with the responsibility for managing these unique habitat types.

In a way analogous to forest environments, forage removals on public lands are the ultimate source of wildlife and fish management issues within rangeland environments. However, rangeland habitat problems appear also to be related to the historical overgrazing of range ecosystems. Attendant with recent declining trends in public-land grazing has been improvement in

range condition. However, because of the slow recovery of vegetation in arid climates, rangeland habitats could still see significant improvements with time and implementation of appropriate management practices. A particularly important wildlife and fish habitat issue associated with range ecosystems is grazing use of riparian habitat. Failure to manage livestock use of riparian areas severely degrades this habitat for both terrestrial and aquatic species.

The majority of big game species have been increasing on national forests and BLM lands in response to the joint habitat and population management between state and federal agencies. Threatened and endangered species are a special responsibility of public agencies, and considerable effort has been exerted to improve the status of these species on public lands through habitat management and the implementation of approved recovery plans.

Recreational use patterns associated with federal lands showed some unexpected trends given the increasing uniqueness of these lands with respect to wildlife and fish habitats and populations. The proportionate number of days spent on federal ownerships has declined slightly for nonconsumptive recreation and big game hunting, and increased for small game and migratory game bird hunting. In the case of national forests, trends in the number of user-days since the last assessment showed declines in nonconsumptive recreation, waterfowl hunting, and small game hunting; increases in big game hunting and warmwater fishing; and stable levels of coldwater fishing.

As land-use intensifies on private lands in response to increasing human populations and increased demand for commodity goods, public lands will probably become more unique with respect to the distribution of native vegetation, wildlife and fish communities, and recreation opportunities. Evaluating the relative importance of public lands to future wildlife and fish recreation and populations requires recreational use and inventory projections.

CHAPTER 2: PROJECTIONS OF WILDLIFE AND FISH RESOURCE USE

Resource-demand projections are an integral part of national resource assessments, and when compared against future trends in resource supplies, they provide insights into possible imbalances between the demand for and supply of natural resources. For wildlife and fish, demand analysis is interpreted to involve projections of resource use (Hoekstra and Hof 1985). This modification on the traditional economic analysis framework is necessary since true demand analysis requires a conventional market structure that generally does not exist for wildlife and fish.

Wildlife and fish use can be categorized into three classes according to the common values held for wildlife and fish resources. These categories are commercial, existence, and recreational values (Hoekstra et al. 1983). The capability to project future trends in wildlife and fish use varies across these categories because data requirements and analysis methods differ.

For commercial fisheries and furbearers, a traditional competitive market exists. However, analyses to project commercial use at scales appropriate for national assessments have not, as yet, been completed.

Existence value represents a category of wildlife and fish use acknowledging that some people derive satisfaction from just knowing that certain species or fauna exist. People hold these values even though they may never use (consumptively or nonconsumptively) the resource directly. Consequently, existence values are independent of current use and expected future use and therefore must be derived from altruistic motives (Randall and Peterson 1984). Passage of such laws as the Endangered Species Act provides evidence for the extent to which existence values are held by the public. Although a general description of existence values is widely accepted, a precise and common definition of the concept does not exist (Bishop 1987). Such a definition is required before future trends in this use category can be analyzed.

In the case of recreational use, standard national surveys addressing wildlife and fish related recreation have been conducted by the Fish and Wildlife Service (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982). These data have been used to examine the correlation between participation levels in recreational activities and socioeconomic factors presumed to be important in explaining why persons choose to participate in certain recreational activities. Projected changes in the socioeconomic factors explaining participation permit an estimation of future users. Because of the analytical constraints associated with commercial use, and because of the need for future theoretical development to address existence value, this chapter only discusses projections of recreational use.

Two aspects of recreational use will be addressed. First, participation in six recreational activities related to wildlife and fish are projected for the nation and each of the four assessment regions. These projections are compared to expected future trends in wildlife and fish recreation on national forests. Second, the growing interest in fee-hunting on private lands is examined as an emerging issue of wildlife and fish recreation. Future trends in the number of hunters participating in fee-hunting are reviewed.

PROJECTION OF WILDLIFE AND FISH RECREATION

Projecting the number of people engaging in wildlife and fish recreational activities provides important information that can be used to anticipate future changes in participation levels and their relative preference for specific recreational activities. The last national assessment of wildlife and fish projected increases for all recreational activities examined (USDA Forest Service 1981). The magnitude of envisioned increases ranged from 90% for freshwater fishing to 24% for small game hunting over a 50-year projection period from 1980 to 2030. These projections were based on linear extrapolations of historical participation rates by age group over the previous 30 years. During this historical period, the number of licensed hunters doubled and the number of licensed anglers more than tripled.

The Fish and Wildlife Service has completed two national surveys on wildlife and fish associated recreation since the 1979 wildlife and fish assessment (USDI Fish and Wildlife Service 1988b; USDI Fish and Wildlife Service, and USDC Bureau of Census 1982). These surveys indicate participation patterns have recently changed. They show declining number of hunters, increasing anglers, and increasing nonconsumptive users. This pattern has been observed by others. Gilbert and Dodds (1987) noted that increasing nonconsumptive interests and a potentially declining number of hunters will change the clientele of the future wildlife manager; in New York, Brown et al. (1987) showed that lower participation in hunting can be expected given sociodemographic trends; and in Colorado, the Executive Task Force on the Future of Wildlife (1987) noted that the number of big game hunters may be expected to decline while participation in fishing and nonconsumptive uses is expected to increase.

Attempting to explain these perceived changes, empirical relationships between participation and hypothesized factors affecting participation were estimated. The projection method reported here was developed by Walsh et al. (1987) and used to analyze nonconsumptive use, coldwater fishing, warmwater fishing, big game hunting, small game hunting, and migratory bird hunting. These activities are defined in table 31.

Projection Approach

Several studies have attempted to project recreational activity at scales appropriate for national assessments (Adams et al. 1973, Cicchetti et al. 1969, Hay and McConnell 1979, Hof and Kaiser 1983). It must be emphasized that these past projections of wildlife and fish use, and the projections reviewed here, do not represent true demand in the economic sense, but rather an estimate of the actual expected consumption. As argued by Hof and Kaiser (1983), if the objective is to identify future over-use problems, then the relevant quantity to project is actual expected consumption not quantity demanded.

For nonmarket goods, such as wildlife and fish, Hof and Kaiser (1983) recommended the following theoretical form for recreation projections:

$$Q_c = f(P, X_i, Q_p)$$

where

Q_c = the quantity of resources actually consumed;
P = a price surrogate, e.g., travel cost or time costs;
X_i = traditional "demand shifters" such as income, age, and education; and
Q_p = the quantity of resource provided or available.

Walsh et al. (1987) followed this theoretical form and examined the relationship between participation in wildlife and fish recreational activities and 20 hypothesized explanatory variables, including two price variables, nine demand shifters, and nine resource availability variables that tended to be activity specific (table 32). Their approach to project Qc (defined as the number of participants) can be summarized in three steps. First, empirical relationships between explanatory variables and the probability that an individual will participate in a given recreational activity were estimated from available data. The data for this study were obtained from the 1980 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982). Logistic regression analysis was used to estimate the projection model coefficients.

The second step involved projection of the explanatory variables from the 1980 base year to 2040. To develop a reasonable range of forecasts that acknowledges the uncertainty about future conditions, three alternative future scenarios were completed. The scenarios resulted in high, medium, and low forecasts of the factors affecting participation in wildlife and fish recreational activities (table 33). The projections of explanatory variables were based on various sources including Darr (in press), USDC Bureau of Census (1984b), Wharton Econometric Forecasting Associates (1985), USDC Bureau of Economic Analysis (1985), and Hof and Kaiser (1983). In general, the medium scenario represented a projection of the recent historical situation. The high and low scenarios assumed an accelerated and slower rate of change, respectively (Walsh et al. 1987). The resource quantity and quality variables were unchanged through the projection period. Consequently, resource availability is not a factor in the projected recreation trends. The impact of changing resource availability (as measured by habitat or animal populations) on recreational use will be addressed in chapter 4.

The third step in the projection methodology was to apply the projected changes in the explanatory variables to the logistic regression equations. The result was an estimated change in the probability of participating in various recreational activities. Total number of participants was calculated by multiplying participation probabilities by the projected human population. To facilitate comparison among recreational activities, relative change from a 1980 base year is shown.

These projections are based on two important assumptions:

1. The relationships between participation in wildlife and fish recreation and socioeconomic factors remain constant over time.
2. Programs are not implemented in the future that either restrict or promote participation in these activities.

Consequently, the trends depicted represent what may occur with the continuation of current management levels and public preferences. Of course, resource management agencies may implement programs to influence or change the course of these trends.

Table 31.—Definitions of the types of fishing, hunting, and nonconsumptive wildlife recreation.

Type of activity	Census survey definition
Nonconsumptive trips	Trips or outings of at least 1 mile from home for the primary purpose of observing, photographing, or feeding wildlife, without which the trip or activity would not have been undertaken. Trips to zoos, circuses, aquariums, and museums, and trips to fish or hunt are not included.
Fishing, total	The sport of catching or attempting to catch fish with hook and line or by archery, spearing, gigging or shooting frogs, seining and netting (but not for bait). Related pursuits that are not considered fishing in the survey include commercial fishing and catching or gathering shellfish (crabs, clams, oysters, etc.).
Coldwater	Includes freshwater trout, kokanee, and anadromous fishes such as salmon and steelhead.
Warmwater	Includes smallmouth and largemouth bass, panfish such as bluegill and crappie, walleye, northern pike, muskellunge, catfish, bullheads, etc.
Hunting, total	The act of searching for wildlife with the intent to take individuals by using firearms or archery. Only hunting for pleasure or recreation is included. Excluded are trapping animals, commercial hunting, searching for animals to photograph, capturing animals live (e.g., to put in a zoo or for biological research), and hunting for frogs. Excluded are those who did not have a weapon but may have accompanied others in the field.
Big game	Large wild animals hunted for sport or food, such as, but not limited to, deer, elk, bear, antelope, and wild turkey.
Small game	Smaller wild animals, such as rabbits, quail, grouse and pheasant, which are hunted for sport or for food; waterfowl, other migratory birds, and animals generally considered to be pests or varmints are excluded.
Migratory birds	Birds regularly moving seasonally from one region or climate to another for feeding or breeding; for example, ducks, geese, doves, and woodcock.

Source: USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

Results

Empirical Relationships

The effect of each explanatory variable on participation levels varies by recreational activity. Walsh et al. (1987) found:

- Price was a significant variable in all recreation activities; as travel cost, licence fees, access fees, and other expenses increase, participation would decline.
- The cross-price variable indicated that nonconsumptive activities and fishing are substitutes for hunting. As a result, if costs associated with hunting increase, then nonconsumptive participation and fishing can be expected to increase.
- Higher income had a positive relationship to participation in nonconsumptive activities, coldwater fishing, and migratory bird hunting. Increased income was associated with lower participation rates in big game hunting. Income was not an important determinant of participation in warmwater fishing or small game hunting.
- Age was related to participation in fishing, big game hunting, and nonconsumptive activities in a quadratic fashion. That is, age was positively related to participation up to a point after which it had a negative relationship. Increasing age had a negative relationship to migratory game bird hunting.
- People living in urban environments were less likely to participate in hunting and fishing activities. However, given that a person is a hunter or fisher, urban residents were more likely to participate in coldwater fishing and migratory game bird hunting, and less likely to hunt big game. Area of residence did not affect participation in nonconsumptive activities, warmwater fishing, or small game hunting.
- Males were more likely to participate in most consumptive activities. However, given that a person is a hunter or angler, a person's sex did not appear to be an important factor explaining participation in big game hunting or warmwater fishing. A person's sex was not important in explaining participation in nonconsumptive activities.

Table 32.—Description of explanatory variables used in recreation projections.

Variable type	Variable name	Definition
Price variables	Price	Average variable cost or miles per participant in respondent's region of residence.
	Cross-price	Average variable cost or miles per participant in other fish and wildlife activities in respondent's region of residence.
Demand shifters	Income	Respondent's gross household income.
	Employment	Respondent worked for wages last week.
	Age	Respondent's age.
	Education	Respondent's education level.
	Marital status	Respondent's marital status.
	Household size	Number of persons living in respondent's household.
	Race	Respondent's race.
	Sex	Respondent's sex.
	Residence	Respondent's place of residence.
Resource quantity, quality variables	Success rate	Average number of fish caught or wildlife bagged per day or season in respondent's region of residence.
	Forest	Forestland, public and private, in respondent's state of residence.
	Range	Pasture- and rangeland in respondent's state of residence.
	Water	Total fishable water in respondent's state of residence.
	Coldwater	Fishable cold water in respondent's state of residence.
	Warmwater	Fishable warm water in respondent's state of residence.
	Habitat	Migratory waterfowl habitat in respondent's state of residence.
	Songbirds	Maximum value of number of songbird species per ecological stratum in state of residence.
	Big game	Population of big game in respondent's state of residence.

Source: Walsh et al. (1987).

- Employment was not shown to affect most consumptive and nonconsumptive recreation.
- Household size was positively related to participation in hunting and nonconsumptive activities.
- Education level was positively related to coldwater fishing and migratory bird hunting and negatively related to small game hunting.
- Resource availability showed the expected positive relationship with participation levels. Consequently, with improved resource management programs, involvement in wildlife and fish recreation should increase.

National Projections

Indexed participation projections are depicted in figure 46. The results indicate that under the medium-level assumptions described above, more people will participate in nonconsumptive activities, cold and warmwater fishing, and migratory bird hunting over the 50-year planning horizon. Coldwater fishing and primary nonresidential nonconsumptive activities have projected gains exceeding 150%. Warmwater fishing is also expected to gain more participants but at a slower rate than coldwater fishing. Migratory bird hunting,

Table 33.—Indexed projections of the explanatory variables under high, medium, and low assumptions.

	Year	National population (millions)	Median age (years)	Race (percent white)	Sex (percent male)	Disposable personal income per capita ($1000's 1982)	Employment (percent employed)	Education (years)	Residence (percent urban)	Marital status (percent married)	Family size (number)	Average variable cost/day (dollars)
Initial condition	1980	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	1990	1.122	1.090	0.979	1.000	1.235	1.069	1.047	0.974	0.998	0.997	1.094
	2000	1.269	1.187	0.959	1.000	1.484	1.107	1.094	0.948	0.980	0.994	1.192
High	2010	1.415	1.227	0.939	1.000	1.773	1.068	1.142	0.923	0.979	0.991	1.266
	2020	1.575	1.223	0.922	1.000	2.052	1.008	1.189	0.897	0.977	0.990	1.326
	2030	1.735	1.243	0.905	1.000	2.461	0.973	1.236	0.871	0.975	0.985	1.402
	2040	1.890	1.237	0.889	1.000	3.016	0.932	1.283	0.845	0.974	0.982	1.479
	1990	1.103	1.100	0.983	1.000	1.213	1.052	1.024	1.001	0.984	0.964	1.077
	2000	1.207	1.210	0.967	1.000	1.432	1.071	1.055	1.003	0.969	0.930	1.153
Medium	2010	1.293	1.283	0.951	1.000	1.721	1.025	1.087	1.004	0.953	0.894	1.230
	2020	1.371	1.310	0.937	1.000	2.022	0.994	1.118	1.005	0.936	0.857	1.306
	2030	1.430	1,360	0.923	0.996	2.420	0.958	1.150	1.007	0.921	0.821	1.383
	2040	1.464	1.387	0.909	0.996	2.961	0.920	1.181	1.008	0.905	0.784	1.459
	1990	1.085	1.107	0.985	1.000	1.181	1.019	1.008	1.026	0.969	0.930	1.042
	2000	1.154	1.233	0.971	1.000	1.361	1.091	1.024	1.052	0.936	0.857	1.097
Low	2010	1.194	1.333	0.957	1.000	1.619	0.972	1.039	1.077	1.905	0.787	1.154
	2020	1.214	1.390	0.943	0.996	1.891	0.932	1.055	1.103	0.872	0.714	1.223
	2030	1.208	1.463	0.929	0.990	2.264	0.895	1.071	1.129	0.841	0.644	1.291
	2040	1.169	1.507	0.915	0.984	2.766	0.858	1.087	1.155	0.809	0.571	1.361

following short-term declines, is the only hunting activity expected to show increased participation by 2040. The number of people participating in big game hunting increases slightly in the short-term but shows a 6% decline over the long-term. Small game hunting is the only activity in which participation consistently declines throughout the projection period with an overall loss of 17%.

The model projections (under the medium-level assumptions) were compared to the preliminary findings from the 1985 survey (USDI Fish and Wildlife Service 1988b). The model was used to predict 1985 participation levels by interpolating between the 1980 base year and the 1990 estimate. The model was consistent in terms of the direction of change (i.e., increases and decreases in participation). However, the model underestimated the change in participation of consumptive activities and overestimated the change in nonconsumptive recreationists (fig. 47).

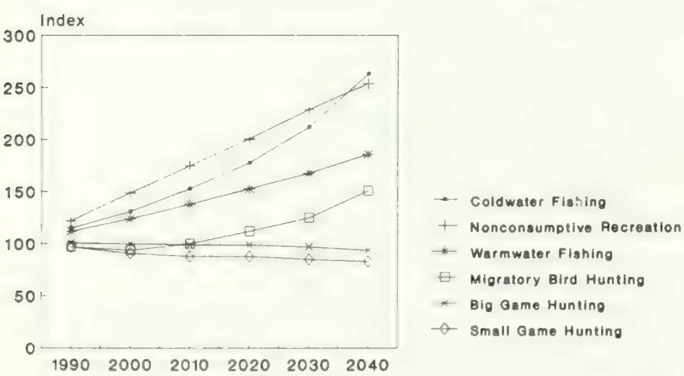
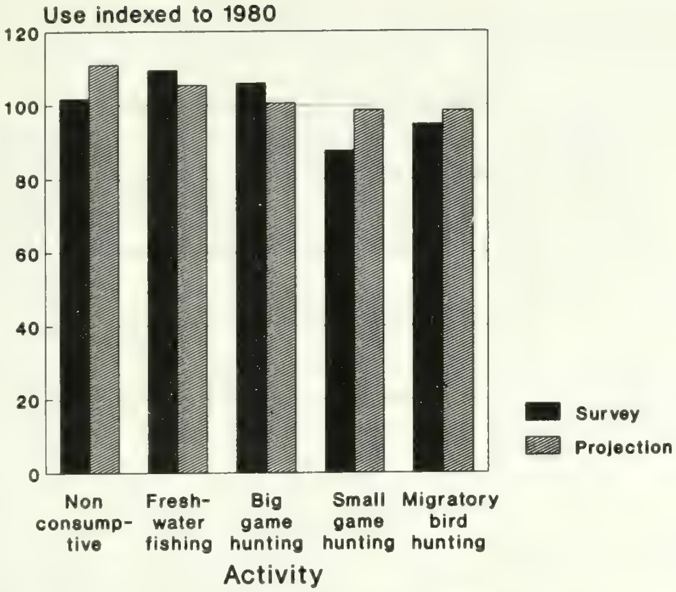


Figure 46.—Projected participation in major wildlife and fish associated recreational activities (Base=1980=100).

The patterns in recreational participation vary under the three alternative future scenarios (table 34). All recreational activities are expected to increase under the high assumption scenario while only nonconsumptive and fishing activities are expected to increase under the low assumption scenario. Despite scenario variation in expected participation levels, all scenarios tend to indicate that hunting, relative to nonconsumptive recreation and fishing, is expected to become less important to the outdoor recreationist.

Regional Projections

Regional wildlife and fish recreation projections were developed by assuming that relative changes in human population levels resulted in an equal percentage change in participation, all other things being equal—a conclusion reached by several studies (Walsh et al. 1987). Regional projections of the price and demand shifting variables were not possible. Consequently, the regional projections of recreation reported here assume no regional variation in the explanatory variables and are



Source: USDI, Fish and Wildlife Service (1988b)

Figure 47.—Comparison of 1985 model projections and 1985 Fish and Wildlife Service survey results.

tied only to regional differences in population growth. Based on the projected changes in the distribution of human populations, the Rocky Mountain region is expected to have the largest increases in wildlife and fish recreation with all recreational activities showing an increase in the number of participants over the 1980 base year (table 35). The Pacific Coast and South also are expected to have greater recreational participation than the national average with all activities except small game hunting showing increases over the base year. In the North, where population growth is expected to be the slowest, the indexed change in the number of participants is lower than was predicted for the nation as a whole.

National Forest Projections

Recreational participation rates on national forests have been projected as part of the forest planning process. These projections show the anticipated levels of wildlife and fish recreational activity indexed to a mid-1980 base year (table 36). National forests are expected to receive increased participation in all recreational activities. Nonconsumptive and recreational fishing are

Table 34.—Indexed projections of the number of participants (Base = 1980 = 100) in major wildlife and fish recreation activities under high, medium, and low scenario assumptions.

			Fishing		Hunting		
	Year	Nonconsumptive wildlife-related trips	Cold-water	Warm-water	Big game	Small game	Migratory birds
Base year use (million)	1980	28.8	6.9	29.5	11.8	12.4	5.3
	1990	125	118	115	102	98	100
	2000	160	141	132	105	96	102
High	2010	193	171	152	108	96	112
	2020	227	207	177	114	101	131
	2030	271	261	205	117	103	154
	2040	319	346	241	121	108	199
Compound annual growth rate		1.952	2.090	1.477	0.318	0.128	1.153
	1990	122	115	112	101	97	97
	2000	149	131	124	100	91	94
Medium	2010	175	153	138	99	88	100
	2020	201	178	153	99	88	112
	2030	229	212	168	97	85	125
	2040	254	263	186	94	83	151
Compound annual growth rate		1.566	1.625	1.040	−0.103	−0.310	0.689
	1990	117	111	110	99	95	94
	2000	136	122	118	95	87	87
Low	2010	155	135	126	91	80	87
	2020	171	149	134	87	77	93
	2030	185	167	139	84	71	97
	2040	194	193	145	74	66	110
Compound annual growth rate		1.111	1.102	0.621	−0.501	−0.690	0.159

Table 35.—Indexed projections of recreational activities (Base = 1980 = 100) by assessment region.

Activity and region	1980 users	1990	2000	2010	2020	2030	2040
	Thousands			*Index*			
Nonconsumptive							
North	[1]14,582	116	136	155	176	198	217
South	7,302	125	137	187	217	250	280
Rocky Mountain	2,949	131	169	205	241	281	315
Pacific Coast	4,431	129	165	196	226	259	288
Big game hunting							
North	5,832	96	91	88	87	84	80
South	4,173	104	105	106	107	106	103
Rocky Mountain	1,412	108	113	116	119	119	116
Pacific Coast	969	106	111	111	112	110	106
Small game hunting							
North	5,707	92	83	78	77	74	71
South	4,766	100	96	94	95	93	92
Rocky Mountain	1,534	104	104	103	106	104	103
Pacific Coast	922	102	101	98	99	96	94
Migratory bird hunting							
North	1,576	93	86	89	98	108	129
South	2,544	100	100	107	121	136	166
Rocky Mountain	736	105	107	117	135	153	187
Pacific Coast	632	103	105	112	126	142	171
Warmwater fishing							
North	([2])	107	113	123	134	146	159
South	—	116	131	148	166	184	205
Rocky Mountain	—	121	141	162	184	207	231
Pacific Coast	—	119	138	154	173	191	211
Coldwater fishing							
North	([2])	109	120	136	156	183	225
South	—	118	139	164	193	231	289
Rocky Mountain	—	123	149	179	218	260	326
Pacific Coast	—	122	146	171	201	240	298

[1]*Nonconsumptive use estimates by region were only available for 1985.*
[2]*Breakdown of total freshwater fishing into cold and warmwater fishing was not possible at the regional level.*
Source: Estimates of actual use are from USDI Fish and Wildlife Service, and USDC Bureau of Census (1982).

expected to increase at the greatest rates over the planning period. The Rocky Mountain region shows the greatest gain in nonconsumptive recreation, small game hunting, waterfowl hunting, and total fishing. The South is expected to have the largest increases in big game hunting. Comparison of the relative rates of participation for national forests with those across all ownerships (see tables 35 and 36) shows that national forests are expected to become relatively more significant in providing opportunities to hunt big game and small game species.

PROJECTION OF FEE-HUNTING ON PRIVATE LANDS

Fee-hunting encompasses numerous access and leasing systems, but generally involves charging the hunter for access to the land and may also include charges for taking of animals. The price that is actually charged is dependent on a number of factors including the game species hunted, success, and services offered by the landowner.

Future participation trends in fee-hunting are important because of the implications to wildlife management on private lands (Ruff and Isaac 1987, Wiggers and Rootes 1987). In addition, future studies of fee-hunting could provide previously unavailable transaction-based estimates of wildlife values that are comparable to other natural resources for use in multiple resource planning (Schenck et al. 1987).

Less than one-third of all hunters used public land in 1980 (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982), emphasizing the importance of private land in consumptive wildlife related recreation. However, access is beginning to constrain the opportunity to hunt on private lands. The National Shooting Sports Foundation (1986) found that of the 19 factors that could curtail hunting, access to huntable land was considered

Table 36.—Projections of recreational wildlife and fish user-days (12-hour activity day) by assessment region on national forests (mid-1980 base year).

Activity and region	Mid-1980 user-days	1990	2000	2010	2020	2030	2040
	Thousands			*Index*			
Nonconsumptive							
North	106	100	112	125	140	159	161
South	192	169	182	193	208	224	240
Rocky Mountain	537	124	150	178	206	235	265
Pacific Coast	509	106	136	154	172	190	210
Big game hunting							
North	1,223	106	112	117	125	129	131
South	2,007	119	125	134	137	139	141
Rocky Mountain	4,562	105	108	113	116	122	127
Pacific Coast	2,821	101	107	111	114	118	122
Small game hunting							
North	984	102	108	116	124	128	133
South	1,691	93	98	103	107	113	119
Rocky Mountain	882	104	114	125	136	146	156
Pacific Coast	500	102	108	111	115	119	123
Waterfowl hunting							
North	188	93	106	120	133	146	160
South	107	104	109	116	121	127	133
Rocky Mountain	197	96	109	122	134	148	161
Pacific Coast	94	106	117	126	133	142	150
Total fishing							
North	2,129	98	113	129	149	153	162
South	2,767	84	89	96	101	108	115
Rocky Mountain	5,749	104	119	133	149	165	182
Pacific Coast	4,960	109	131	139	147	155	163

the number one problem facing hunters nationwide. Fee-hunting could change the trend in access to private lands because private landowners who previously denied access may be more willing to exchange permission for remuneration. However, fee-hunting could further compound the access problem. For example, after surveying all 50 states Wiggers and Rootes (1987) found that lease-hunting resulted in more private land opened for hunting in 12 states while four states reported declines.

In 1980, 1.4 million hunters (8% of all hunters) paid either access or lease fees (Langner 1987a). Lease agreements have increased over the last 10 years and are most prevalent in the South and Mid-Atlantic regions according to Wiggers and Rootes (1987), who also speculated that two important factors influencing the prevalence of fee-hunting were a lack of public land and high human populations. Langner (1987a) substantiated these speculated relationships empirically and found that not only did a high percentage of private land increase the probability of participation in fee-hunting, so did hunter experience, education level, and total travel-related hunting expenditures. Income level was also an important factor explaining whether or not a person fee-hunted (Langner, pers. comm., 1987b).

Langner's modeling approach was identical to that of Walsh et al. (1987), and it predicted participation in fee-hunting given that a person was a hunter. Projections of fee-hunting participation thus required projections of explanatory variables and the total number of hunters. Projections of income, education, and travel-related expenditures were taken from table 33 under the medium assumption scenario. Hunter experience and percent land in public ownership were assumed to remain constant. The projected number of total hunters was calculated using the model developed by Walsh et al. (1987).

Application of these assumed changes to the fee-hunting model indicated that the number of hunters participating in some form of fee-hunting could increase more than 150% by 2040 (fig. 48). The proportion of hunters participating in fee-hunting is expected to increase to an even greater degree since the total hunting population is expected to increase only slightly. Based on these results, approximately one in every five hunters may be participating in fee-hunting by 2040.

SUMMARY

Wildlife and fish resource use projections were based on empirical models developed from established national surveys of participation in wildlife and fish recreational activities. These models do not project demand in the economic sense but rather project expected levels of use (measured as number of participants)

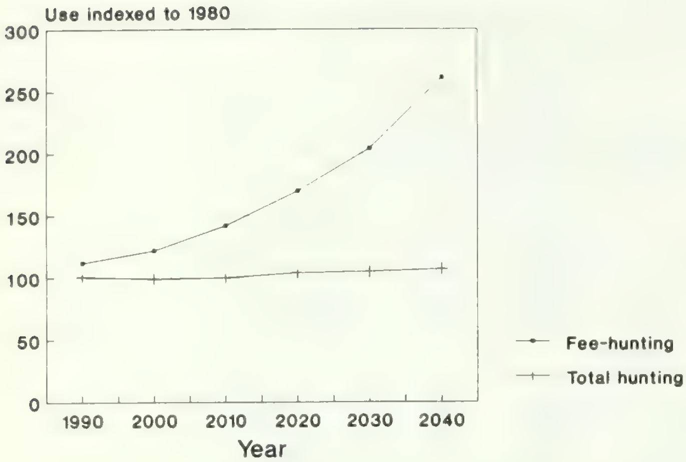


Figure 48.—Projected participation in fee-hunting compared to total hunting.

based on changes in demographic and socioeconomic determinants of participation. The projections assume no direct intervention on the part of resource managing agencies that will either restrict or promote future participation. Rather, the projections reported here examine future trends in wildlife and fish recreation if we assume a continuation of current management levels and public preferences.

The results indicate that the relative importance of various recreation activities related to wildlife and fish will shift. Coldwater fishing and nonconsumptive activities could increase at the greatest rate with the number of participants more than doubling by 2040. In general, hunting could become relatively less important as the number of big game and small game hunters decline. More hunters will probably participate under fee-hunting situations in the future. As many as one in five hunters may be participating in some form of fee-hunting by 2040.

Comparing the future trend of wildlife and fish recreation on all ownerships with that expected on national forests, as determined from the forest planning process, indicates that these public lands will become more important in providing outdoor recreation for big game and small game hunters. Mandates requiring multiple resource planning on national forests will help maintain the amounts and quality of future wildlife and fish habitats and also continue to provide the public with opportunities for nonconsumptive and consumptive recreational activities involving wildlife and fish resources.

CHAPTER 3: PROJECTIONS OF WILDLIFE AND FISH RESOURCE INVENTORIES

Projections of wildlife and fish inventories have been difficult to address analytically (Crawford 1984, Hench et al. 1985). This difficulty has limited the incorporation of wildlife and fish objectives into multiple resource planning (Thomas 1986). The data bases and modeling capabilities to support forecasts of wildlife and fish inventories vary depending on the resource attribute of interest. Land-use projection models provide some insights into likely future habitat trends, and regional habitat-based wildlife and fish abundance models have been developed to evaluate land use and land management impacts for a limited number of regions and target species. To present the most complete set of inventory projections covering as many species and as much geography as possible required supplementing conventional analysis with the judgment of resource professionals.

This chapter summarizes the results from the application of these various inventory projection approaches at the national and, where possible, regional level. Inventory projections are discussed for three attributes of wildlife and fish resources. First, habitat is considered by reviewing land use and land cover changes. Second, population is discussed based on information from state and federal agencies and an application of regional habitat-based wildlife and fish abundance models in the South. Third, future wildlife harvest trends are examined.

PROJECTIONS OF HABITAT INVENTORIES

Projected wildlife habitat availability was based on expected changes in land-use and land-cover categories as surrogates for an explicit projection of wildlife and fish habitat. Although land-use and land-cover estimates provide previously unavailable information on future wildlife habitat, they only coarsely indicate how land types and the intensity of land management are expected to change. Explicit statements of wildlife habitat trends will require further research on species-habitat relationships and a commitment to multiple resource considerations at the outset of the analysis.

Overview of Land Use Changes

As part of the resource assessment analysis, the Forest Service recently predicted that the area of major land-use and land-cover categories will change (Bones in press) (table 37). The prediction was based on assumptions about various demographic, social, and economic variables (Darr in press). Forestland is expected to decline slightly over the next 50 years with an overall 4% loss. This represents a continuation of the gradual decline noted during the recent history. Where forestland losses were attributable to cropland conversions during the 1980's, forestland reductions after 1990 are ascribed primarily to urban expansion and reservoir construction (Bones in press).

Rangeland area could increase by approximately 5% as a result of cropland reverting back to rangeland. The increase is expected for two reasons: (1) diminishing surface and subsurface water supplies with an associated rising cost of water could reduce land in irrigated agriculture, and (2) the Conservation Reserve Program is expected to convert substantial acres of highly erodible cropland to permanent grass cover. A more detailed discussion of rangeland area changes and factors explaining these changes can be found in Joyce (in press).

The crop and pasture land projections depicted in table 37 show an overall loss of 94 million acres (an 18% reduction) by 2040. The Conservation Reserve Program has the greatest short-term impact as highly erodible cropland is converted to permanent cover. Other factors also contribute to the decline, such as natural reversion to native vegetation as irrigated acres decline, and conversion to urbanland uses continues. Reduced cropland also has been projected by other resource management agencies. The second appraisal for the Soil and Water Resources Conservation Act (USDA Soil Conservation Service 1987) projected that acres actually planted to crops could decline from 370 million acres to 347 million acres nationwide by 2030.

The increase in "other" land uses will be dominated by the dynamics of urbanland uses. The urbanization of

Table 37.—Major land-use acreage trends for the United States from 1987–2040.

Year	Forest[1]	Range	Crop[2]	Other[3]	Total[4]
			Million acres		
1987	727	770	528	232	2,257
2000	715	809	470	260	2,254
2010	711	809	460	272	2,252
2020	707	809	451	283	2,250
2030	703	810	443	292	2,248
2040	699	810	437	301	2,247

[1]*Includes transition zones, such as areas between heavily forested and nonforested land.*
[2]*Pastureland is included.*
[3]*Includes urban and other land categories.*
[4]*Total area declines due to increased water areas.*
Source: Bones (in press).

rural lands causes particular concern because the conversion is essentially permanent and the associated changes in habitat quality extend beyond urban boundaries. Increased disturbance from humans and domestic animals, conversion of natural vegetation communities, and potential declines in water quality all tend to shift the composition of the animal community to more common native or exotic species that are more adaptable to urban environments (DeGraaf 1986).

The regional shifts in major land uses show the potential for greater land area changes than at the national level (table 38). Regional changes in the commercial timberland acreage portion of the forestland base indicate that all regions could experience acreage reductions over the projection period. The decline in commercial timberland, relative to the acres present in 1982, is expected to be the greatest in the Pacific Coast and the smallest in the Rocky Mountains. The South will probably lose the greatest absolute area (approximately 9 million acres) of commercial timberland as a result of urban expansion and some conversion to cropland (Bones in press).

Regional rangeland area is projected to show significant increases early in the projection period in response to the Conservation Reserve Program (table 38). Acreage increases will be focused in the Rocky Mountain and Southern regions. After the year 2000, rangeland area could decline slightly in the Rocky Mountains and the North but continue to increase slightly in the South and Pacific Coast.

Effects of a Federal Program: The Food Security Act of 1985

The projected changes in the terrestrial land base presented here are based on recent surveys and analyses and suggest a different land base future than has been judged by others in past national reports on wildlife habitat (see Frayer 1987; National Academy of Sciences, National Research Council 1982). Important land-use policy changes are responsible for the new perception of the future. An important policy change with the potential to significantly improve the amounts and condition of wildlife and fish habitat resulted from the Food Security Act of 1985 (also called the 1985 Farm Act). This Act contains several conservation programs directed at reducing soil erosion which may secondarily benefit wildlife and fish habitat.

An important provision of this new policy, the Conservation Reserve Program (CRP), is intended to remove highly erodible cropland from production. The Secretary of Agriculture is authorized to enter into contracts with farmers to take erosion-prone acres out of crop production for a period of at least 10 years. The farmer receives annual rent payments, technical assistance, and cost-sharing payments (up to 50%) to convert these acres into permanent grass or tree cover.

The CRP is anticipated to encourage the conversion of 40 to 45 million acres by 1990. Most of these acres will be converted to grasses. As of the fifth sign-up period (August 1987), about 23 million acres had been

Table 38.—Projection of regional timber and range land uses from 1982–2040.

Land type Region	1982	2000	2010	2020	2030	2040
			Million acres			
Commerical forest						
North	153	152	151	150	149	148
South	194	189	188	187	185	185
Rocky Mountain	61	60	60	60	59	59
Pacific Coast	72	70	69	69	68	67
Range						
North	0.4	0.3	0.3	0.2	0.2	0.2
South	116	128	128	129	130	130
Rocky Mountain	413	440	439	438	437	436
Pacific Coast	241	241	242	242	243	244

Source: Bones (in press).

enrolled with the average size per contract being 110 acres though not necessarily as a continguous land unit. The major crop types that had been affected through the fourth sign-up, in rank order, were wheat (42% of all base acres contracted), corn (23%), sorghum (12%), and barley (11%).

Farmer participation at the regional level has varied. The greatest interest has occurred in the Rocky Mountain region, particularly the Great Plains states where about 10 million acres have been enrolled. The Northern and Southern regions have approximately 5 and 6 million acres under contract, respectively. The Pacific Coast has 1.5 million acres currently enrolled. Based on the projected changes in cropland acres, wildlife and fish habitat will be influenced most significantly in the Rocky Mountains, and next most importantly in the South and North.

Three additional conservation provisions complement CRP objectives: the "Sodbuster," "Swampbuster," and Conservation Compliance programs. The Sodbuster and Swampbuster provisions deny eligibility to receive federal farm subsidies, including price support payments, crop insurance, disaster payments, and low interest loans to those farms that plow new, highly erodible land, or convert wetlands to annual crop production. The Swampbuster provision is particularly important since agricultural development is the major recent cause of wetland drainage and clearing (see chapter 1; Office of Technology Assessment 1984).

The Conservation Compliance provision requires those who produce crops on highly erodible land to comply with an approved conservation plan in order to remain eligible for USDA farm program benefits. Based on the Soil Conservation Service 1982 National Resources Inventory (USDA Soil Conservation Service and Iowa State University Statistical Laboratory 1987), 117.6 million acres of highly erodible cropland existed in 1982. Treatment of these lands through implementation of an approved conservation plan or through enrollment in the CRP could greatly reduce the off-site deposition of sediments to other lands and especially to aquatic ecosystems.

Prior to the passage of this law, perceptions of the amount and quality of future waterfowl and upland game habitat were discouraging. That negative outlook was based on expected increases in cropland acreage, decreased wetland acreage, and increased use of intensive management practices on cropland, forestland, and rangeland (National Academy of Sciences, National Research Council 1982).

Frayer (1987) projected wetland acreage based on a continuation of historical trends between the mid-1950's and the mid-1970's. In that analysis, vegetated palustrine wetlands were estimated to lose 5.5 million acres between 1974 and 2000 (table 39). These changes include 3.8 million acres of forested palustrine wetlands and 1.7 million acres of emergent palustrine wetlands.

Table 39.—Projections of area of wetland types for the conterminous United States 1974–2000.

Wetland type	1974	1986	1990	1995	2000
	Thousand acres				
Estuarine wetland	5,243	4,923	4,850	4,765	4,686
Palustrine open water	4,393	5,599	5,998	6,494	6,987
Palustrine flat	577	641	663	690	717
Palustrine forested	49,713	47,824	47,262	46,584	45,932
Palustrine scrub-shrub	10,611	10,955	11,065	11,200	11,333
Palustrine emergent	28,441	27,559	27,297	26,989	26,701
Total	98,978	97,501	97,135	96,722	96,356

Source: Frayer (1987).

The non-vegetated and open water wetland types were projected to increase in acreage between 1974 and 2000, due to the anticipated creation of pond and reservoir wetland categories.

The wetland projections made by Frayer (1987) exclude expected changes in land use stemming from recent legislation or regulations. The Swampbuster provision of the Food Security Act of 1985, therefore, has the potential to significantly alter Frayer's projections. The possible benefits attributable to this provision can be evaluated by examining recent estimates for the amount of wetland habitat that could be converted to cropland. The Soil Conservation Service 1982 National Resources Inventory identifies nearly 5.2 million acres of nonfederal wetlands classified as having a medium to high potential for conversion to cropland (table 40). Determining those wetlands with potential for drainage was based on the wetland types that were drained in the recent past.

The potential for additional wetland drainage varies by region. The greatest acreage of remaining nonfederal wetland that could be drained occurs in the Northern and Southern regions (table 40). Small amounts of nonfederal wetlands are suitable for drainage in the Rocky Mountain and Pacific Coast regions. However, relative to the total nonfederal wetland area remaining, over 12% could be lost in the Pacific Coast. The Swampbuster provision of the Farm Act was established to stop the incentives paid to private landholders who would convert these forest and range wetlands into cropland.

Table 40.—Nonfederal wetlands with potential for conversion to cropland.

Region	Total wetland acres	Wetland acres with potential conversion to cropland	Percent of total
		Thousand acres	
North	26,183	1,587	6.1
South	38,735	2,518	6.5
Rocky Mountain	8,544	758	8.9
Pacific Coast[1]	2,570	319	12.4
Total	76,032	5,184	6.8

[1]*Excludes Alaska and Hawaii.*

Source: USDA Soil Conservation Service, and Iowa State University Statistical Laboratory (1987).

The potential impact of the Food Security Act on improving wildlife and fish habitat is significant. Substantial increases in upland habitat associated with agricultural lands, maintenance of wetland acres, and sizable reductions in soil erosion could prove beneficial to small game, nesting waterfowl, nongame animals, and fish. Whether this potential is realized depends on several factors. Under Gramm-Rudman-Hollings budget restrictions, future appropriations could be reduced (Cubbage and Gunter 1987) thereby lessening the effectiveness of the conservation programs. Increases in commodity prices could decrease farmers' dependence on federal subsidies. Alternatively, hunter participation in lease agreements which, unlike timber harvesting and grazing, is permitted under the Food Security Act, could provide increased incentive for farmers to manage for wildlife habitat on their lands. Finally, questions arise concerning the long-term implications to wildlife and fish habitat following the 10-year contract period. When all of these considerations are brought together, the future habitat impacts ascribable to the Food Security Act, while providing reason for optimism, are subject to considerable uncertainty.

PROJECTION OF POPULATION INVENTORIES

Information on future wildlife population levels was available from several sources. State wildlife and fish agencies provided both short-term (1995) and long-term (2040) projections of wildlife populations. The National Forest System (NFS) and Fish and Wildlife Service provided additional sources for projections stemming from their management responsibility. A fourth contribution came from regional habitat-based population models. These models were developed and used to predict wildlife and fish abundance changes in response to land use and timber management changes across all land ownerships in the South (Flather et al. in press, Flebbe et al. 1988).

Table 41.—Indexed projections in big game populations by region (Base = 1985 = 100), with number of states contributing to regional mean shown in parentheses.

Region Species	1995	2040
North		
Wild Turkey	153 (8)	214 (7)
White-Tailed Deer	102 (9)	97 (7)
Black Bear	109 (5)	107 (5)
South		
Wild Turkey	128 (7)	122 (5)
White-Tailed Deer	114 (9)	111 (8)
Black Bear	133 (4)	150 (3)
Rocky Mountain		
Wild Turkey	203 (5)	208 (5)
Deer	114 (11)	115 (10)
Elk	125 (8)	144 (7)
Pronghorn	101 (10)	115 (9)
Black Bear	106 (5)	105 (5)
Pacific Coast		
Wild Turkey	198 (2)	198 (2)
Deer	99 (3)	100 (4)
Elk	110 (1)	107 (2)
Pronghorn	100 (1)	100 (2)
Black Bear	120 (1)	110 (2)

State Agency Population Projections

The projections provided by the state wildlife and fish agencies contributed the most complete geographical information. The short- and long-term percentage change estimates from 1985 represent professional judgement on the likely future condition of selected big game and small game populations. These estimates considered historical population trends, likely future land-use changes, and proposed wildlife management practices. State estimates were summarized as a regional mean of reporting states weighted by the 1985 animal population level within each state. In general, most state agencies are optimistic that populations will increase for both big and small game in the next 10 years, with some exceptions.

Big Game

Eastern big game populations could be generally higher in the future (table 41). Wild turkey is one species for which important increases are forecasted. The substantial historical increase noted in the North (see chapter 1) is expected to continue through 2040. Projected turkey increases in the South, although more moderate than in the North, also represent a continuing historical trend. Several factors influence the expected changes in wild turkey populations. Translocation as a management practice and immigration into suitable habitats could contribute to future population growth.

White-tailed deer in the North could maintain their mid-1980's population with regional estimates ranging within 3% of the 1985 estimates. The maturing forests, lower rates of farm abandonment, and less timber

harvesting contribute to stable deer populations in the North. In the South, white-tailed deer populations are expected to show slight increases through 2040.

Black bear populations in both the North and the South could moderately increase. In the short-term, the expected increase in the North will be slightly more conservative than in the South. In the long-term, both regions could realize less than a 10% increase from 1985 population levels.

The Rocky Mountain states expect, in general, greater short- and long-term gains in big game populations than were reported in the East (table 41). Wild turkey populations are expected to double in the short-term on the Great Plains with little additional increase expected by 2040. As in the East, increased turkey populations will come from translocation practices and natural immigration.

Future population increases for the region's three most abundant ungulates will range from 44% for elk to 15% for deer and pronghorn. Elk populations could gradually and consistently increase over the next 50 years. This growth will result from continuing the favorable habitat conditions and successful population management strategies implemented during the last 20 years. Modest increases in deer (both mule and white-tailed) populations are foreseen with mountain states expected to do better than the plains states. More plains states reported future deer declines, possibly due to anticipated conversion of cropland acres to permanent grass under the Conservation Reserve Program. Pronghorn populations could remain stable over the next 10 years. However, from 1995 to 2040 both mountain and plains states express mixed expectations about pronghorn numbers with the regional average trend being slightly upward.

In the Pacific Coast region, only the wild turkey could show significant changes from the mid-1980's population level. Turkey populations could nearly double over the next 10 years. All other big game species, including deer (mule, black-tailed, and white-tailed), elk, pronghorn, and black bear could remain at 1985 population levels or increase slightly (not exceeding 10%) by 2040. No clear geographic pattern, habitat factor, or management action explains why the states anticipate the changes they have reported with the exception of wild turkey, the expanding populations of which are a product of the nationwide management attention this bird has received and will continue to receive.

Small Game

Most small game species are projected to either remain stable or increase over 1985 population estimates (table 42). Northern bobwhite are a notable exception to this pattern. Over the species' primary range, populations could continue the decline that has occurred over the last 20 years. Although the rate of decline is less than in recent history, the bobwhite is not expected to recover to 1985 population levels.

In the South, all the small game species for which projections were available showed short-term declines or

Table 42.—Indexed projection in small game populations by region (Base = 1985 = 100), with number of states contrib g to regional mean shown in parentheses.

Region / Species	1995		2040	
North				
Forest Grouse	110	(5)	101	(4)
Pheasant	120	(2)	150	(1)
Quail	93	(3)	93	(3)
Rabbit	112	(3)	106	(3)
Squirrel	105	(3)	120	(3)
South				
Forest Grouse	100	(2)	120	(2)
Quail	94	(5)	94	(3)
Rabbit	98	(4)	106	(2)
Squirrel	95	(4)	98	(2)
Rocky Mountain				
Forest Grouse	100	(2)	100	(2)
Prairie Grouse	98	(4)	97	(4)
Pheasant	189	(5)	185	(5)
Quail	123	(5)	115	(5)
Rabbit	154	(2)	208	(2)
Squirrel	117	(3)	117	(3)
Pacific Coast				
Forest Grouse	100	(1)	100	(2)
Prairie Grouse	120	(1)	109	(2)
Pheasant	101	(2)	120	(3)
Quail	([1])		100	(1)
Rabbit	100	(1)	100	(1)

[1] *No data provided.*

stable population levels. Quail show the greatest decline, followed by squirrels and rabbits. Only rabbits and grouse are expected to exceed the mid-1980's population by 2040.

In the North, only the bobwhite could decline. Ruffed grouse populations could remain relatively stable over the projection period. Stable grouse populations appear related to the low level of forest regeneration in general, and in particular, the recent loss of the aspen-birch forest type. Anticipated pheasant population gains in the North are attributed to improved upland habitat quality associated with the CRP. Although the CRP's long-term impacts remain unknown, state wildlife agencies expect pheasants to increase consistently through 2040. Rabbit populations could show moderate short-term gains, then dwindle to mid-1980's levels in the long-term. Squirrel populations could grow 5% per decade over the 50-year projection period, mostly because of maturing forests.

The anticipated expansion of intensive management for southern forests, greater human population increases in the South compared to the North, and further maturing of the northern hardwood forests collectively explain the disparate small game projections for these eastern regions. Similarly, differences in the perceived habitat improvement benefits stemming from the CRP explain differences in projected species responses. While the pheasant could respond favorably to the CRP, the bobwhite probably will not because overhead cover requirements provided by woody shrub species is less likely

to develop on CRP acres during the 10-year contract period.

In the Rocky Mountain region, states are optimistic about all upland small game populations except for prairie grouse species (table 42). Most species could experience modest increases over the next 10 years and these gains could either be maintained or increase further in the long-term.

The majority of the small game populations in the Pacific Coast region could remain stable over the projection period. Pheasant and prairie grouse are exceptions to this pattern with regional population gains of 20% for prairie grouse in the short-term, and for pheasant in the long-term.

National Forest System Population Projections

As part of the Forest Planning process, individual national forests are required to project the likely future status of natural resources. For this assessment, a combination of habitat models and professional judgment was used to project big game population. The majority of species could increase in response to proposed management activities (table 43).

Black-tailed deer, a mule deer subspecies typically managed as a distinct group, presents a major exception. Although the combined trend for Forest Service Region 5 (California and Hawaii) and 6 (Oregon and Washington) is slightly upward, combining across regions masked important differences in this case. In Region 6, black-tailed deer populations are expected to decline by nearly 20% over the projection period. Presumably, this trend is owed to changes in forest succession. Early stages of secondary succession following logging develop into midsuccessional stages unfavorable to black-tailed deer. Region 5 populations could increase by approximately 25%, which more than offsets the declines noted in Region 6. All other Pacific Coast big game populations could increase or remain stable over the 50-year planning period.

All other assessment regions anticipate big game increases. The South shows substantial long-term gains in wild turkey, white-tailed deer, and black bear. The population increases on national forests are predicted to be relatively greater than total increases anticipated by state agency personnel. Consequently, NFS lands will tend to support a greater proportion of the South's big game populations. This scenario appears consistent with the expected intensification of timber management on private land in this region.

As in the South, big game populations on northern national forests could consistently increase over the projection period. For all species except wild turkey,

Table 43.—Regional big game population trends for national forests.

Region Species	Mid-1980	1990	2000	2010	2020	2030	2040
				Thousands			
North							
Wild Turkey	34	52	53	54	55	56	56
White-Tailed Deer	327	321	327	334	340	347	354
Moose	6.6	6.5	6.6	6.6	6.7	6.8	6.9
Black Bear	11.8	9.8	10.3	10.9	11.4	11.9	12.5
South							
Wild Turkey	123	253	258	275	283	289	291
White-Tailed Deer	281	392	290	405	436	437	440
Black Bear	3.7	5.4	6.2	6.3	6.5	6.6	6.8
Rocky Mountain							
Wild Turkey[1]	59	134	139	144	148	153	158
Mule Deer	1,055	1,152	1,181	1,196	1,218	1,238	1,260
White-Tailed Deer[2]	284	304	317	320	322	325	327
Elk	408	476	496	511	527	541	556
Bighorn Sheep[2]	16	28	29	31	31	31	32
Pacific Coast[3]							
Wild Turkey	8.3	10.8	12.2	14.3	16.3	18.4	21.5
Mule Deer	336	338	376	382	386	392	398
Black-Tailed Deer	412	407	441	433	425	421	423
White-Tailed Deer	16	16	16	16	16	16	16
Elk	94	95	96	98	99	100	101
Bighorn Sheep	2.0	2.0	2.1	2.2	2.3	2.4	2.5
Black Bear[4]	17	17	17	17	17	17	17

[1]*Data from Forest Service Regions 2 and 3.*
[2]*Data from Forest Service Regions 1, 2, and 3.*
[3]*Data from Forest Service Regions 5 and 6.*
[4]*Data from Forest Service Region 6.*

increases are slight (less than 10%). Wild turkey numbers could increase by 62% on national forests compared to a total 114% increase projected by state personnel.

All big game species on national forest lands in the Rocky Mountain region could show long-term population increases. However, the relative increases may be either equal to or more moderate than those anticipated across all regional ownerships. Deer population projections on national forests, relative to mid-1980's levels, show a gain equal to that anticipated by state agency personnel. Wild turkey and elk show lower relative increases on national forests compared to state agency data.

Fish and Wildlife Service Population Projections

As one of the federal government's lead agencies for fish and wildlife conservation and management, the Fish and Wildlife Service must prepare various resource management plans. One common component of these plans is the specification of future wildlife and fish resource status. Future status is often defined as habitat, population, or harvest objectives to be reached through implementation of management activities. In other cases, future status is described as a continuation of recent trends. This section summarizes the findings from two national plans, one on waterfowl and one on fishing.

The North American Waterfowl Plan (USDI Fish and Wildlife Service and Canadian Wildlife Service 1986a) aims to restore those duck and goose populations which have declined recently (see chapter 1), and it also calls for maintaining current numbers for all other waterfowl species. The plan has a 15-year horizon, to the year 2000, and proposes habitat acquisition, improvement, and restoration to accomplish the population objectives. Under the assumed implementation strategy, the Fish and Wildlife Service projects that breeding population levels for the 10 most common species of ducks will increase from the 27 million birds observed in 1985 to 36 million by 2000. Successful implementation depends, to a large degree, on funding. Since cost estimates for plan implementation exceed anticipated federal appropriations, the private sector and states will play a critical role in meeting funding requirements.

To assess the nation's future hatchery fish requirements, the Fish and Wildlife Service conducted a national survey (USDI Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife 1968b). The findings from this survey indicate that fishable water is expected to increase from 87.1 million acres in 1980 to 104.6 million acres by 2040—an overall increase of approximately 20%. This projection was based on water quality improvements on streams and lakes, accelerated stocking programs, and expected reservoir construction.

Habitat-Based Abundance Projections for the South: A Case Study

Past assessments of natural resources have relied on a limited application of analytical approaches to project resource supplies and inventories. Assessments have also been criticized for not analyzing resource response in a multiple resource context (Schweitzer et al. 1981). In response to such criticism, Joyce et al. (1986) developed a regional modeling framework designed to analyze multiple resource responses to land management activities. The southern United States was chosen as a test area for application because this region was already the focus of a regional study of timber resources. The combining of these two efforts resulted in the first regional evaluation of timber resources that also analyzed multiple resource impacts stemming from timber management actions and changing land use (USDA Forest Service 1988). This case study represents a prototype of how future national assessments may address regional multiple resource analyses.

Linking wildlife and fish resources into the multiple resource framework required the capability to predict resource response to general land management activities. The objective of the wildlife and fish modeling component was to develop regional abundance and occurrence models that were consistent with and responsive to models that projected regional shifts in land use and timber inventory characteristics. Models were developed for white-tailed deer, wild turkey, red-cockaded woodpecker, and trout. A detailed description of the wildlife and fish models can be found in Flather (1988), Flather et al. (1989), and Flebbe et al. (1988).

Projection Approach

The description of a species' habitat depends on the scale of the resource management problem. At a regional scale, patterns in land use and forestland characteristics define a coarse representation of wildlife and fish habitat. For fish, this approach represents an extension of within-stream habitat models to consider changes in the watershed land base where streams occur.

The modeling approach is patterned after Klopatek and Kitchings (1985) and uses discriminant function analysis to establish statistical relationships between land use and forestland descriptors, relative abundance classes of white-tailed deer, wild turkey, and trout, and occurrence of active red-cockaded woodpecker nesting colonies. The wildlife models used counties as the sampling unit while the fish model used watersheds defined by the U.S. Geological Survey.

Land base data were obtained from Forest Service inventories (USDA Forest Service 1985a) for area estimates of commercial timberland for forest cover types (natural pine, planted pine, oak-pine, upland hardwood, and lowland hardwood) and forest age classes. The Soil Conservation Service's 1982 National Resource Inventory (USDA Soil Conservation Service and Iowa State University Statistical Laboratory 1987) was used to estimate area in all other land types including cropland, pastureland, rangeland, and human-related land uses (urbanland, roads, railroads, farm structures, strip mines).

Projected changes in land use and land cover (i.e., forest type, cropland, pastureland, rangeland, and

human-related land uses) were provided by a land area projection model developed by Alig (1984). Changes in forest age classes were provided by the timber resource inventory model (Tedder et al. 1987). Projected changes in the land base were applied to the wildlife and fish models to estimate the impacts on the wildlife and fish species that were modeled. The result is an indexed projection of wildlife and fish abundance or occurrence in future years compared with the 1985 base year. Separate projections for the Southeast (Virginia, North Carolina, South Carolina, Georgia, and Florida) and South-central (Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Tennessee, and Alabama) were made for the wildlife species. Trout projections are reflective of the coldwater fishery area in the southeast.

Results

To accomplish the objective of modeling the possible impacts of changing land use and forest vegetation characteristics on wildlife and fish abundance and occurrence, a number of assumptions were required. These assumptions acknowledge those factors which influence wildlife and fish numbers and habitat relationships but which cannot be incorporated into the modeling framework. Quantified characterization and inclusion of these assumptions into regional models will require further research. The specific ecological assumptions made in this analysis were as follows:

1. Wildlife and fish populations used in establishing the habitat relationship models occurred at the habitat's carrying capacity.
2. Wildlife and fish population changes predicted over the projection period (1985–2030) are due solely to changes in land use and forestland characteristics. Consequently, factors other than habitat, including competition, harvest rates, and wildlife and fish population management practices, are assumed to remain constant over the projection period.

These are obviously simplifying assumptions; although changes in factors are likely, data were not available to incorporate their influence into species habitat relationships or to project their influence over time. In addition, the wildlife and fish modeling effort represents an impacts analysis that is entirely driven by the land use and the timber inventory projections. Feedback mechanisms, whereby the wildlife and fish responses alter the timber resource and timber management activities, are being considered for future research.

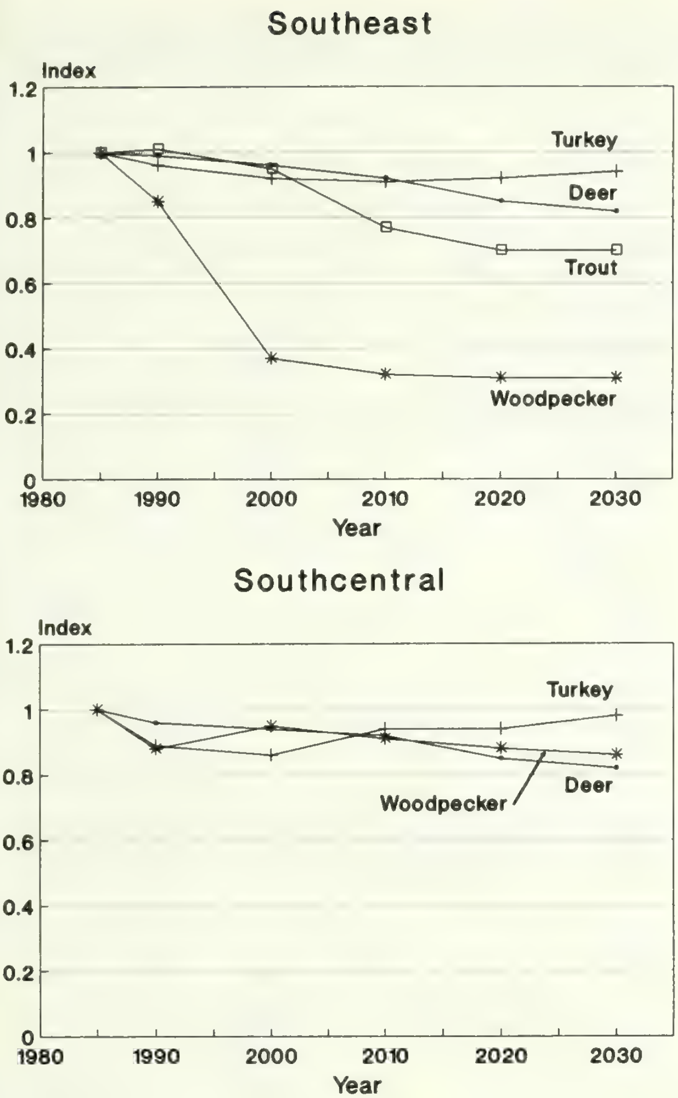
In light of these assumptions, projections were made for a baseline condition representing the likely future demand for timber products and what level of timber management would be required to ensure that timber supplies would meet that demand. The land area changes under this likely future baseline condition for the Southeast and South-central between 1985 and 2030 are summarized in table 44. The overall land use and forest type patterns are similar across the two regions and the projected trends indicate more intensive forest management and more human dominated land uses. Forest area in general, and to a lesser degree pasture, declined over the projection period. Cropland showed only slight increases in the South-central region. Area of human-related land uses showed relatively large increases across both subregions. The most notable forest type changes that occurred were conversion of natural forest types to pine plantations. Natural pine accounts for the majority of the converted acres; however, oak-pine and upland hardwood types also were harvested and planted to pine. The major changes in forest stand structure involved gains in younger forest age classes in both subregions, and increases in older hardwood age classes in the South-central.

Table 44.—Projected land area changes (percent of total land base) in the South between 1985 and 2030.

	Southeast		South-central	
	1985	2030	1985	2030
Total cropland	14.6	14.6	18.5	18.9
Total pasture/range	12.9	12.1	17.8	14.5
Human-related land	9.0	12.3	5.9	9.9
Total forestland	57.8	55.3	54.9	53.7
Natural pine	14.6	7.6	11.1	7.2
Planted pine	8.5	15.7	4.6	14.1
Oak-pine	6.6	6.7	9.7	6.5
Upland hardwood	18.7	17.2	20.2	17.4
Lowland hardwood	9.4	8.1	9.3	8.5
Age class 1 (0–20 yrs.)	10.3	15.1	16.6	18.6
Age class 2 (20–50 yrs.)	24.2	14.9	31.3	15.0
Age class 3 (50+ yrs.)	14.8	9.6	2.4	6.0
Hardwood age class 1	6.4	11.1	12.5	14.1
Hardwood age class 2	14.7	11.3	24.7	12.5
Hardwood age class 3	13.5	9.6	2.1	5.8
Pine age class 1	5.8	6.7	8.1	7.3
Pine age class 2	12.8	7.5	12.1	5.8
Pine age class 3	2.6	0.1	0.5	0.5

The wildlife and fish responses to these land base changes are shown in figure 49. White-tailed deer, a species with relatively general habitat requirements, was not closely correlated in its response to changes in any single land cover characteristic. Deer are projected to experience approximately 18% density declines in both subregions. The decline was attributed to an overall loss of forested habitat acres, specifically upland hardwoods and the conversion of natural pine and oak-pine stands to planted pine. Increased acreage in human-related uses including urbanland and roads also contributed to the overall decline in deer numbers. Human-related land use not only directly reduces available habitat but is generally associated with higher mortality resulting from increased hunting pressure and human-related disturbance.

Wild turkeys have more specific habitat requirements than deer and were closely tied to the hardwood component of the forestland base. Increased human-related land use acres and the general loss of upland hardwood and oak-pine types contributed to the early decline. However, after the year 2000, average turkey density increased slightly in the Southeast and recovered in the



Source: Flather et al. (1989); Flather (1988); Flebbe et al. (1988)

Figure 49.—Projected changes in wildlife and fish abundance under the baseline conditions for the Southeast and South-central regions.

South-central in response to increased acreage of older hardwood stands.

The red-cockaded woodpecker showed the greatest decline of all species in the Southeast. Projections were made for the occurrence of active nesting sites within a county. The number of counties supporting active nesting colonies declined by nearly 70% in the Southeast and 20% in the South-central. The red-cockaded woodpecker has highly specialized habitat needs. Mature pine stands are required for nesting habitat. The decline followed conversion of mature natural pine to planted pine on private plantations. The leveling off in the number of counties supporting active colonies happened because of the expected retention of mature pine stands on federal ownerships, particularly national forests.

As was observed with the wildlife species, trout abundance in the coldwater region of the Southeast also declined. The approximately 30% decline reflected a decrease in the older age classes of hardwoods and increased area in human-related land uses. Implicit in these relationships are factors such as water temperature, instream cover, and shading that are favorable for trout under older hardwoods and unfavorable under most land cover other than forests.

The habitat-based abundance results for white-tailed deer and wild turkey are more pessimistic than the state agency projections. Under an assumed future of increased urbanization and more intensive timber management, both big game species are predicted to decline. However, the habitat-based models predict what may occur if no consideration is given to future wildlife management activities directed at altering the projected trends. For this reason, the projections reflect only a potential future for deer and turkey in the South. State and federal agencies have the option to intensify deer and turkey management to offset perceived declines, and this may be reflected in the projections provided by these agencies. Similarly, private landowners may find increased economic incentive (e.g., trespass fees, hunter lease agreements) to manage their lands for wildlife production. What this analysis has shown is that increased management expenditures and more intensive wildlife and fish management likely will be required in the future if deer, turkey, and trout populations and suitable nesting sites for red-cockaded woodpeckers are to be maintained in the South.

PROJECTION OF HARVEST INVENTORIES

Projections of future harvests were obtained from state and federal wildlife agencies. Because harvest is more easily monitored than populations, many wildlife management agencies use harvest as an indicator of wildlife population status. State and NFS personnel provided estimates of the likely future harvest based on anticipated changes in animal populations, available habitat, and participation rates in hunting. The Fish and Wildlife Service projected future duck harvests under assumed implementation of the North American Waterfowl Plan.

State Agency Harvest Projections

Estimates of harvests for 1995 and 2040 were treated in the same manner as state agency population projections. State estimates of the percentage harvest change from 1985, for each species, were summarized as a regional mean that was weighted by 1985 harvest estimates. In general, state agencies expect harvest levels for the majority of species to increase. All of the notable declines in future harvests were reported for small game species primarily associated with agricultural habitats.

Big Game

Big game harvests are regulated to a greater degree than are harvests of small game species. For this reason, the projected harvests of big game are affected by both

harvest regulations and animal population level. Most big game harvests could increase by 1995 (table 45) and the majority by more than 20%. The Pacific Coast region, in general, is an exception to this pattern. Deer and elk harvests could increase slightly by 1995 declining toward 1985 levels by 2040. Bear harvests could remain stable throughout the projection period. Wild turkey is the only big game species in the Pacific Coast region for which harvests could increase significantly—nearly doubling by 1995.

Wild turkey harvests across all regions will show the most consistent and largest relative short-term increases. Both the North and Rocky Mountain regions expect increases of about 40% by 2040. Turkey harvests in the South could increase 50% by 1995, yet the increase will probably not last over the projection period but decline to within 15% of 1985 levels.

Deer harvests in the East could increase by 1995 and then remain stable through the remainder of the projection period. Deer harvests in the Rocky Mountains could increase similarly to the East by 1995. However, short-term gains may not be maintained as projections by 2040 decline to 1985 harvest levels. Given that western deer populations are projected to remain stable from 1995 through 2040, declining harvests may reflect expected declines in the number of future big game hunters pursuing deer.

Harvest projections for the remaining big game species in the Rocky Mountain region are generally optimistic. Steady increases are expected for elk harvests through 2040 for all reporting states. Pronghorn harvests could increase in the short-term. The long-term projection for pronghorn is mixed in terms of the magnitude and the geographic location of the change, but on average is expected to decline slightly compared to 1995 estimates.

Small Game

Species which associate with either agriculture or forest could experience some short-term declines in harvest levels (table 46). The majority of these declines are minor with the exception of the quails. Northern bobwhite harvests are expected to decline by approximately 15% in the South while quail harvests in the Pacific Coast are expected to drop 50%, both by 1995. Lower quail harvests are expected to continue over the projection period in all regions with the Pacific Coast, Rocky Mountain, and Southern regions expecting long-term declines greater than 20%. Declining quail harvests were expected given the previously noted population declines.

Other species for which slight harvest declines are anticipated by 1995 include ruffed grouse and squirrel in the North, and rabbit and squirrel in the South. The trends for squirrel and rabbit harvests are consistent with the habitat trends in the South. Estimates of future ruffed grouse harvests are difficult to interpret based on either habitat or hunter effort since they demonstrate cyclic population patterns that have yet to be satisfactorily explained.

Table 45.—Indexed projection in big game harvests by region (Base = 1985 = 100), with number of states contributing to regional mean shown in parentheses.

Region Species	1995	2040
North		
Wild Turkey	114 (9)	139 (7)
White-Tailed Deer	123 (13)	121 (11)
Black Bear	125 (6)	110 (5)
South		
Wild Turkey	152 (8)	115 (9)
White-Tailed Deer	128 (8)	126 (6)
Black Bear	139 (4)	179 (3)
Rocky Mountain		
Wild Turkey	136 (10)	143 (9)
Deer	128 (11)	118 (11)
Bear	123 (5)	99 (4)
Elk	114 (8)	139 (7)
Pronghorn	125 (11)	117 (10)
Pacific Coast		
Wild Turkey	196 (3)	195 (4)
Deer	106 (3)	102 (4)
Elk	106 (1)	102 (2)
Pronghorn	([1])	100 (1)
Black Bear	100 (1)	100 (2)

[1]*No data provided.*

Table 46.—Indexed projection in small game harvest by region (Base = 1985 = 100), with number of states contributing to regional mean shown in parentheses.

Region Species	1995	2040
North		
Grouse	97 (8)	100 (6)
Pheasant	136 (9)	122 (7)
Quail	98 (9)	86 (8)
Rabbit	113 (10)	103 (9)
Squirrel	98 (10)	107 (9)
South		
Grouse	100 (1)	125 (1)
Quail	84 (6)	79 (4)
Rabbit	102 (4)	103 (3)
Squirrel	99 (6)	109 (4)
Rocky Mountain		
Forest Grouse	224 (8)	215 (7)
Prairie Grouse	143 (9)	92 (8)
Pheasant	142 (10)	122 (9)
Quail	99 (8)	77 (9)
Rabbit	153 (9)	143 (8)
Squirrel	117 (8)	113 (8)
Pacific Coast		
Forest Grouse	110 (1)	108 (2)
Prairie Grouse	100 (1)	100 (2)
Pheasant	99 (3)	99 (4)
Quail	50 (2)	59 (3)
Rabbit	103 (2)	102 (2)
Squirrel	100 (1)	100 (1)

Pheasant and prairie grouse harvests could increase over the primary ranges largely because of increased habitat and subsequent population growth derived from the CRP. The gain is primarily a short-term expectation.

Harvests after 1995 depend on the longevity of the CRP and accessibility of private lands to small game hunters.

National Forest System Harvest Projections

Future big game harvests on national forests (table 47) are generally correlated with anticipated increases in populations. The one exception is Pacific Coast black bear harvests which could increase despite stable populations over the projection period (table 43). All other big game species could experience consistent gains in harvest over the 50-year planning period. The greatest harvest increases, relative to the mid-1980's estimate, could occur with wild turkey in all regions, black bear in the Pacific Coast and South, and bighorn sheep in the Rocky Mountains. Mule deer could show the greatest absolute harvest increase in the Rocky Mountains.

In general, the relative increase in big game harvests from the national forests is greater than the totals reported by state agencies. Consequently, national forests could become more important to big game hunters. An important causal factor that may affect this projection is limited private land access. This observation is amplified in the west where, historically, the harvest of some big game species has come almost exclusively from federal ownerships (Hoekstra et al. 1981).

Fish and Wildlife Service Harvest Projections

As described under the population projection section of this chapter, the Fish and Wildlife Service has set harvest objectives for waterfowl under assumed implementation of the North American Waterfowl Plan (USDI Fish and Wildlife Service and Canadian Wildlife Service 1986a). The harvest objectives specified in the plan would permit 2.2 million hunters to harvest 20 million ducks annually, for an average seasonal harvest of 9.1 birds per hunter by the year 2000. Realization of these objectives is contingent upon full completion of the management schedule for purchase, protection, and improvement of approximately 5.5 million acres of waterfowl habitat in the United States and Canada.

SUMMARY

Wildlife and fish resource inventory projections were based on professional judgments and empirical models. The results from these various analyses indicate that the South and Rocky Mountain regions will have the most significant future land base changes. The South is expected to lose acres in natural vegetation cover to urban and cropland development. The Rocky Mountain region, which includes the Great Plains, is expected to experience the largest increases in the rangeland base due to plantings associated with the Conservation Reserve Program under the 1985 Farm Act. Other Farm

Table 47.—Regional big game harvest trends for national forests.

Region Species	Mid-1980	1990	2000	2010	2020	2030	2040
			Thousands				
North							
Wild Turkey	5.7	5.7	5.8	5.9	6.0	6.2	6.2
White-Tailed Deer	54	55	56	57	58	59	60
Moose	0.32	0.39	0.40	0.40	0.40	0.41	0.41
Black Bear	1.3	1.3	1.4	1.5	1.5	1.6	1.7
South							
Wild Turkey	10	27	29	32	33	34	35
White-Tailed Deer	49	57	59	62	64	65	66
Black Bear	0.45	0.70	0.82	0.86	0.96	1.0	1.4
Rocky Mountain[1]							
Mule Deer	166	168	175	181	187	193	199
White-Tailed Deer	41	42	45	45	46	46	46
Elk	61	62	64	66	67	70	71
Bighorn Sheep[2]	0.22	0.23	0.24	0.26	0.27	0.29	0.30
Pacific Coast[3]							
Wild Turkey	0.19	0.66	1.7	2.5	3.1	3.8	4.7
Mule & Black-Tailed Deer	55	60	64	65	68	69	72
Elk	16	16	16	17	17	17	18
Black Bear[4]	1.3	1.4	1.5	1.6	1.7	1.8	2.0

[1]*Data from Forest Service Regions 1, 2, and 4.*
[2]*Data from Forest Service Regions 1 and 2.*
[3]*Data from Forest Service Regions 5 and 6.*
[4]*Data from Forest Service Region 6.*

Act conservation programs also have the potential to significantly reduce the rate at which wetland habitats are converted to cropland, and also to reduce the sedimentation of wetlands and other aquatic habitats.

Wildlife population projections provided by state agencies tended to be consistent with the projected changes in habitat. All big game populations and harvest levels for which information was available are expected to increase or remain stable over the 50-year projection period. The future for small game populations and harvests is less optimistic. Historical declines in northern bobwhite populations and harvests are expected to continue. Pheasant populations and harvests, however, are projected to respond favorably in all regions to increased habitat resulting from the CRP.

The state agency projections implicitly consider the effects of planned wildlife management activities on future wildlife populations. Analyzing the impacts of changing land use and timber management while holding wildlife and fish management constant was the subject of a case study (and regional prototype for future assessments) in the South. Projections of white-tailed deer, wild turkey, red-cockaded woodpecker, and trout distribution and abundance indicated that all species could decline in the future. The results of this case study demonstrated that under expanding human populations and more intensive timber management, more intensive wildlife and fish management will be required to maintain or improve future wildlife and fish populations.

Wildlife and fish inventory projections provided by federal managing agencies indicated that national forest lands will continue to become more important to wildlife and fish resources in the future. Objectives specified by the Fish and Wildlife Service under two national plans, if realized, are expected to reverse the declining trends in waterfowl populations and harvests that have been observed in the recent past, and to increase the amount of fishable waters.

CHAPTER 4: COMPARISON OF RESOURCE INVENTORY AND USE PROJECTIONS

An important question to be addressed by natural resource assessments is whether future resource supplies are capable of supporting future levels of resource demand. The economic theory that supports supply-demand comparisons of commodity resources is not applicable to resources that are not produced, bought, or sold in a traditional competitive market. Consequently, for wildlife and fish, such comparisons are based on projected levels of resource use and inventories. Wildlife and fish recreational use and resource inventories have been projected as independent quantities in chapters 2 and 3. To make inventory-use comparisons, an analysis approach is required that converts units of use (number of recreationists) and units of inventory (number of animals, acres of habitat) into a common base.

The approach used in the 1979 national assessment for big and small game hunting compared the projected percentage change in wildlife populations to the projected percentage change in the number of hunters (USDA Forest Service 1981). Although such comparisons indicated change in the potential consumptive pressures placed on wildlife populations, the approach failed to acknowledge that participation in wildlife and fish recreation depends partly on resource availability (Hay and McConnell 1984, Hof and Kaiser 1983, Walsh et al. 1987).

This assessment uses a different approach to make inventory-use comparisons. As described in chapter 2, Walsh et al. (1987) developed a series of models that empirically related participation in wildlife and fish recreational activities with factors thought to be important in explaining that participation. Resource supply was one factor explicitly used in these models, and this inclusion allowed an examination of how changes in resource supplies might alter participation in wildlife and fish recreational activities.

The recreational use projections reviewed in chapter 2 presented expected levels of participation in major wildlife and fish recreational activities due solely to socioeconomic determinants of recreation preferences and recreation participation rates. These projections are interpreted to represent a *base level* participation that could be expected assuming a future level of resource inventory similar to that which was available to recreationists in the past. Changing the level of resource availability not only acknowledges the uncertainty associated with the future status of wildlife and fish inventories, but also provides a means to examine situations where future resource inventories may not be sufficient to meet projected base level participation.

This chapter is organized into three major sections. First, the resource supply variables for each wildlife and fish recreational activity are defined and reviewed. This is followed by an analysis of the sensitivity of projected participation in wildlife and fish recreation to hypothetical alternative future wildlife and fish resource inventory situations. The final section addresses the degree to which habitat, population, and harvest changes projected in chapter 3 will affect future participation in wildlife and fish recreational activities, and the degree to which base level use (demand) will be met by future resource inventories (supply).

INDICATORS OF WILDLIFE AND FISH RESOURCE SUPPLIES

Habitat area affects wildlife and fish population levels, which in turn affect the resource available for viewing by nonconsumptive recreationists and harvest by anglers and hunters. Past studies of factors affecting participation in wildlife and fish recreational activities have acknowledged the relationship between habitat and animal populations. Typically, they used acres of habitat, abundance of wildlife, or harvest success rates interchangeably to examine resource supply effects on recreational opportunities and the quality of the recreational experience. The indicators of resource supply reported here are those that Walsh et al. (1987) found to be important, based on statistical criteria, in explaining participation in wildlife and fish recreation.

Although one or several of the basic supply indicators listed above were incorporated into each model, the actual supply indicator used varied by recreational activity reflecting, in part, basic differences in the factors affecting participation in each activity.

For primary nonresidential nonconsumptive recreation, total acres of forest, pasture, and range in each state were used as the resource supply proxy. These land types collectively represent a basic measure of the amount of natural habitats available to wildlife, which are in turn the output sought by the nonconsumptive recreating public. Forestland was defined to include all areas at least 10% covered by trees of any size. Pasture and rangeland were defined as areas predominantly vegetated by grasses, legumes, forbs, or shrubs suitable for grazing but excluding land used for orchards, vineyards, or other crops. It was assumed that increases in more intensive land uses (e.g., cropland and urbanland) would decrease the opportunity to participate in, and the attractiveness of an area for, primary nonresidential nonconsumptive activities.

Participation in hunting was also affected by the amount of public and private forest, pasture, and range in each state. Although some cropland is used for hunting, Walsh et al. (1987) assumed that increases in cropland area tends, in general, to destroy game habitat. McConnell (1984) found that increasing the amount of cropland decreased the likelihood of persons engaging in hunting activities.

Resource supply indicators for specific hunting activities included:

Big game hunting.—Total population of deer, elk, moose, pronghorn, black bear, bighorn sheep, mountain goat, boar, and wild turkey within the respondent's state of residence.

Small game hunting.—Average number of small game harvested per day in the respondent's region of residence.

Migratory bird hunting.—Average number of migratory game birds harvested per day in the respondent's region of residence.

Participation in fishing was affected by the acreage of fishable water available to potential anglers in each state. Fishable water area was chosen as the appropriate supply indicator over total inland water area since only 73% of the streams sampled in the National Fisheries Survey (Judy et al. 1984) were found capable of supporting sport fish populations during some portion of the year. Failure to sustain game fish was attributed to intermittent flows and water quality problems (see chapter 1).

Participation in coldwater fishing was further affected by the proportion of fishable waters specifically capable of supporting a coldwater fishery. State estimates of the proportion of total fishable waters suitable for coldwater fishing were used to estimate the availability of coldwater fish habitat (Resources for the Future 1980). Participation in warmwater fishing had a stronger statistical relationship with the average number of warmwater fish species taken per day than the availability of warmwater fish habitat.

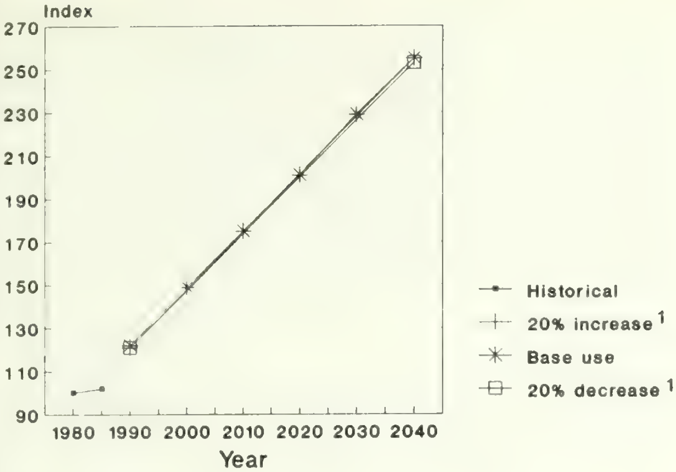
In addition to the statistical criteria used in selecting resource supply variables, data availability also limited the full suite of potentially important resource supply indicators that could be examined. For example, the actual land area open to the recreating public would be a better indicator of resource availability than total forest, pasture, or range, particularly in the East where private land ownership dominates. Similarly, area of habitat of varying quality would also be a likely important indicator of resource supply. However, nationally complete information on each state's land area open to the public or the amount of habitat in various quality classes was not available. Consequently, potentially better indicators of resource supply are definable, yet current inventory information does not support an examination of their effect on participation in wildlife and fish recreational activities at this time. This fact should be kept in mind when interpreting the relative sensitivity of each recreational activity to changes in resource supply.

SENSITIVITY OF RECREATIONAL USE TO CHANGES IN RESOURCE SUPPLIES

Potential changes in public participation in wildlife-related recreational activities that could be attributed to resource management activities were evaluated by altering the level of the resource supply indicators within the recreation participation models developed by Walsh et al. (1987). Resource management activities that could be interpreted as beneficial or detrimental to wildlife and fish habitat or populations were represented by assuming a 20% increase or decrease in the activity-specific supply indicators. The number of recreationists under inflated and deflated resource supply conditions were compared to the base level projections reviewed in chapter 2 to measure the sensitivity of each activity to changes in resource supply. The sensitivity of each recreational activity to changes in resource supply are shown in figures 50–55. Each figure shows the recent historical participation from chapter 1, the base level use projection from chapter 2, and projections depicting the sensitivity of each recreational activity to changes in resource supply. Participation levels have been indexed to a 1980 base year which was set to 100 to facilitate comparison across recreational activities. Equal portions of the assumed change in resource supply indicators are applied to each decade such that the total change in resource supply by 2040 is equal to 20% of the base year.

Nonconsumptive Wildlife-Related Recreation

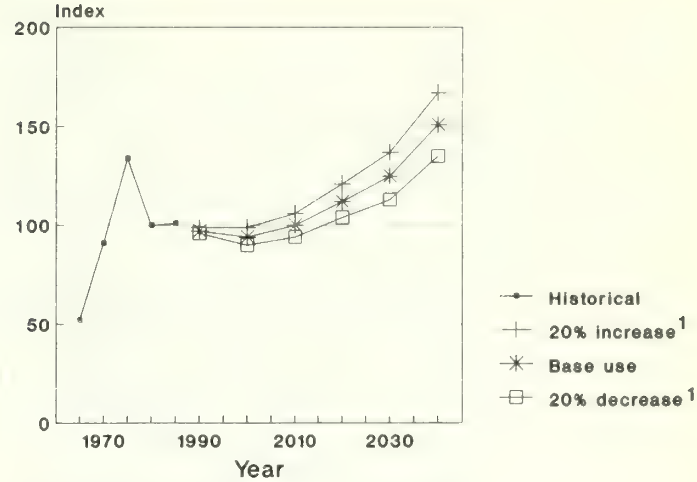
Primary nonresidential nonconsumptive wildlife recreation was not sensitive to a 20% change in the amount of forest, pasture, and range (fig. 50). Hay and McConnell (1984) also found that resource availability was not an important factor explaining participation in nonconsumptive wildlife recreation. The low sensitivity of primary nonresidential activities to changes in resource supply may be a function of two factors. It may



[1]Use based on 20% increase or decrease in resource inventories.

Source: USDI, Fish and Wildlife Service and USDC, Bureau of Census (1982); USDI, Fish and Wildlife Service (1988b)

Figure 50.—Sensitivity of primary nonresidential nonconsumptive recreation to changes in resource supply (Base = 1980 = 100).



[1]Use based on a 20% increase or decrease in resource inventories.

NOTE.--Historical trends based on participants 12 years old and older that hunted waterfowl

Source: USDI, Fish and Wildlife Service (1988b)

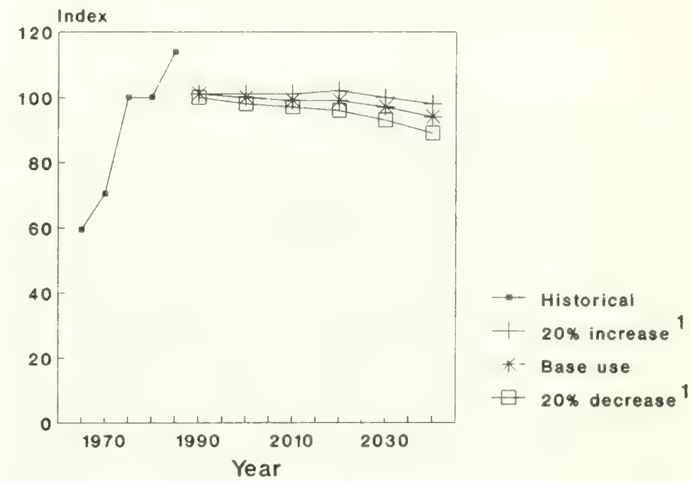
Figure 51.—Sensitivity of migratory bird hunting activities to changes in resource supply (Base = 1980 = 100).

indicate that an appropriate measure of resource supply has not yet been specified, or it may be that current resource supplies are more than sufficient to support current recreational activity. Considering that nonconsumptive activities are less constrained to a particular season, current opportunities to observe, photograph, or study wildlife may be sufficient to support current public demand for primary nonresidential activities. Determining whether model misspecification or sufficient supplies is the reason for the observed relationship will require further research.

Recreational Hunting

Hunting activities tended to be more sensitive to changes in resource supply than nonconsumptive activities although specific types of hunting vary considerably. Migratory game bird hunting was the most sensitive with a 20% increase in resource supply resulting in a greater than 10% change from base level participation (fig. 51). The habitat supply indicator for migratory game bird hunting is measured as the amount of forest, pasture, and range acres within a state. A wetland habitat variable was examined but found to be insignificant in explaining participation in migratory game bird hunting (Walsh et al. 1987). A similar observation was made by Miller and Hay (1981) and may be related to the inclusion of webless migratory game bird hunters (e.g., woodcock and dove hunters) in this category of recreational use.

Big game hunting was the second most sensitive activity to changes in resource supply (fig. 52). A 20% change in acres of forest, pasture, and range habitats and in big game populations resulted in a 5% change in the number of big game hunters. A major assumption in the



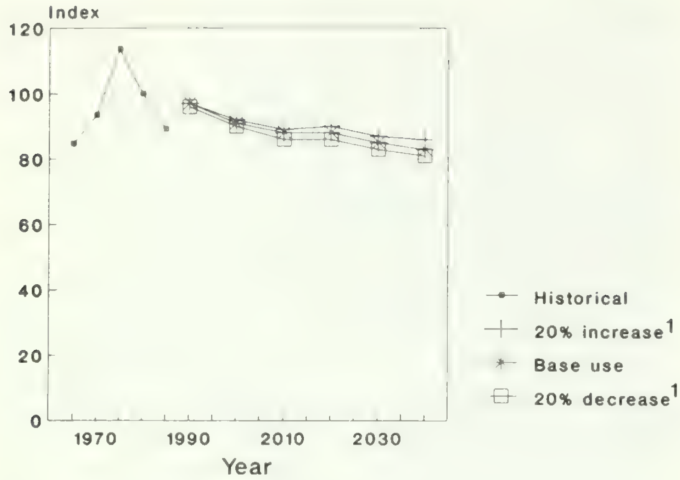
[1]Use based on 20% increase or decrease in resource inventories.

NOTE.--Historical trends based on participants 12 years old and older

Source: USDI, Fish and Wildlife Service (1988b)

Figure 52.—Sensitivity of big game hunting activities to changes in resource supply (Base = 1980 = 100).

analysis of big game hunting was that increases or decreases in animal populations were important information used by potential big game hunters in deciding whether or not to participate. Given the noted concerns for decreased accessibility to hunting land, crowded hunting conditions (National Shooting Sports Foundation 1986), and the projected increases in hunter lease agreements, future big game participation may become

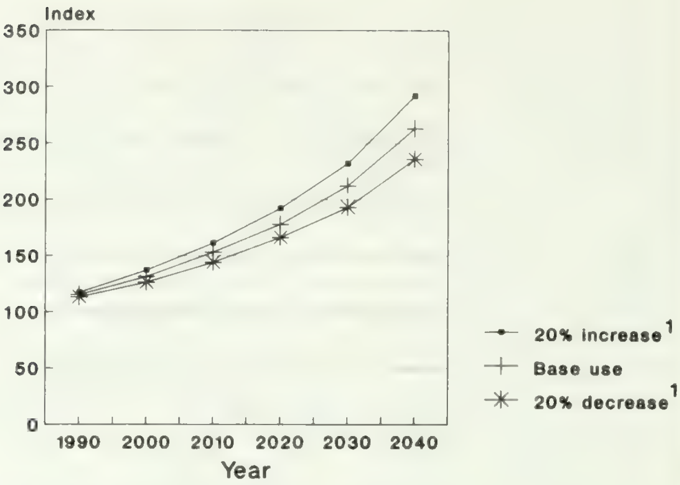


[1]Use based on a 20% increase or decrease in resource inventories.

NOTE.--Historical trends based on participants 12 years old and older

Source: USDI, Fish and Wildlife Service (1988b)

Figure 53.—Sensitivity of small game hunting activities to changes in resource supply (Base = 1980 = 100).



[1]Use based on a 20% increase or decrease in resource inventories.

Figure 54.—Sensitivity of coldwater fisheries to changes in resource supply (Base = 1980 = 100).

more dependant on accessible game and lease prices than total game populations.

Small game hunting was least sensitive to changes in resource supply (fig. 53). The assumed 20% change in forest, pasture, and range habitat and in the number of small game animals harvested per day translated into a 4% change in the number of small game hunters compared to the base level projection. Small game hunting was the only wildlife-related recreational activity for which statistically significant relationships between participation and an activity-specific measure of resource supply could not be found (Walsh et al. 1987). The lack of significant relationships between recreation use levels and resource supply probably indicate that more appropriate measures of small game resource supply exist. As reviewed in chapter 1, the evidence suggests that declines in small game hunters results from limited access to suitable habitat, increasingly crowded hunting conditions, and declining game populations (National Shooting Sports Foundation 1986). Apparently, current supplies are insufficient to maintain the quality of the recreational experience. Although the actual availability of small game habitat and populations and levels of crowding are difficult to measure, such indicators of supply may more accurately reflect the resource supply determinant of participation in small game hunting. An additional consideration is that the analysis of small game use may be too coarse. It may not adequately account for the potential differences in the factors that determine whether, for example, a quail hunter or squirrel hunter decides to hunt.

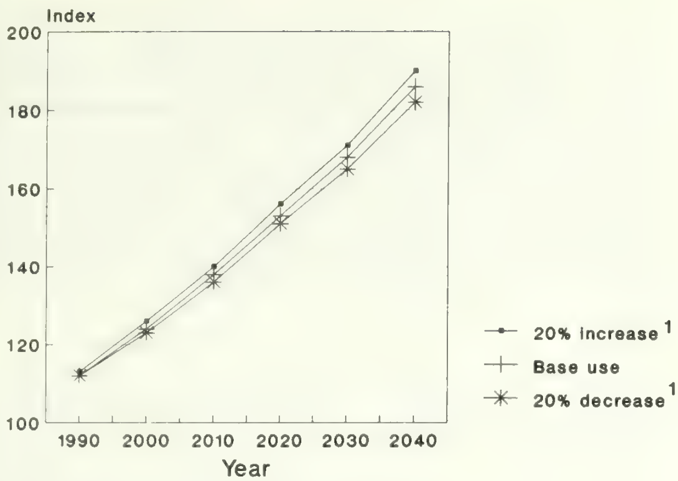
Recreational Fishing

Coldwater fishing on inland waters (excluding saltwater and Great Lake fishing) was found to be more sensitive to changes in the resource supply indicators than was warmwater fishing. An assumed 20% change in the proportion of a state's fishable waters suitable for coldwater fishing resulted in nearly an 11% change from the base level condition (fig. 54). Comparisons to historical trends were not possible since the National Survey of Fishing and Hunting (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982) did not differentiate between cold- and warmwater fishing. Coldwater fishing was the most sensitive recreational activity to changes in resource supply. Observed participation could deviate dramatically from the base level projection in response to the future availability of fishable waters.

The decision of whether to participate in warmwater fishing was a function of both the amount of fishable water in general, and specifically the number of warmwater fish species caught per day. Warmwater fishing appears to be less sensitive to shifts in resource supply with a 20% change yielding only a 2% shift in the number of warmwater fishers (fig. 55).

IMPLICATIONS OF RESOURCE INVENTORY PROJECTIONS ON RECREATIONAL USE

Sensitivity analysis indicated the relative magnitude of recreational use response to hypothetical changes in resource supply indicators. Incorporation of resource inventory projections into the inventory-use comparison approach previously outlined provides an opportunity to examine whether anticipated levels of resource inventories will meet base level projections of resource use.



[1]Use based on a 20% increase or decrease in resource inventories.

Figure 55.—Sensitivity of warmwater fisheries to changes in resource supply (Base = 1980 = 100).

Increasing human populations imply that future recreationists will each find less habitat and fewer animals. Accounting for the per capita availability of resources has been shown to be important in capturing the effect of crowding on the availability of recreation opportunities (Hay and McConnell 1984, Walsh et al. 1987). Based on this logic, wildlife and fish inventory-use comparisons would be better based on two alternative resource supply situations. The first would be to predict the number of recreational participants, assuming that habitat and animal populations will be maintained, resulting in a per capita decline in the future availability of resource supplies. The second would be to examine participation levels using the projected habitat and animal populations provided by federal and state resource managing agencies. This latter projection represents the future status of wildlife and fish resources assuming implementation of state and federal management programs. These two comparisons, reviewed below, provide one evaluation of the extent to which future resource management will meet anticipated levels of use.

Declining Per Capita Resource Availability

Dividing the various resource supply indicators for each recreational activity by the projected human population level (see table 33, medium level assumptions) results in a 32% decline in wildlife and fish resources available to each potential recreationist by the end of the projection period (year 2040). Migratory game bird hunting and coldwater fishing show the greatest declines from the base condition (table 48). The crowded conditions implied under this analysis result in at least a 10% decline in the number of coldwater fishers and migratory bird hunters. More moderate declines in the number of big game hunters and small game hunters are noted. Warmwater fishing showed the least percentage decline from the base condition of all the consumptive recreational activities. Nonconsumptive recreation showed essentially no deviation from the base level use projection—an expected result given the low sensitivity of nonconsumptive recreation to shifts in resource supply.

State and Federal Agency Projections of Resource Inventories

Given the declining participation under the per capita resource availability projection, a legitimate question arises. To what extent will anticipated land base changes and planned wildlife and fish management activities support a greater level of recreational participation than that projected under the declining per capita availability of resources? In other words, what proportion of the recreational user "gap" depicted in table 48 will be eliminated by future resource management activities?

The land base, population, and harvest projections are reviewed in detail in chapter 3. A brief national summary is presented here. The amount of land classified as forest, pasture, or range is expected to change little over the projection period of this report. The 26 million acre decline in forest area and the 40 million acre increase in pasture and range results in a 1% net gain

Table 48.—Comparison of national base level recreational use projections to projected use under declining per capita availability of resources at 2040 (Index = 1980 = 100).

Use projection	Nonconsumptive recreation	Coldwater fishing	Warmwater fishing	Big game hunting	Small game hunting	Migratory game bird hunting
Base level[1]	254	263	186	94	83	151
Per capita resource availability	253	232	179	87	79	127
Difference	1	31	7	7	4	24
(% of Base)	*	(12)	(4)	(7)	(5)	(16)

[1]*From chapter 2.*
Less than 1%.

in land area capable of supporting wildlife and fish recreational activities. Changes in aquatic habitat (defined as fishable water) could potentially increase by 20% according to the USDI Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife (1968b). For this analysis, the 20% gain in fishable water was assumed to be distributed equally among both cold- and warm-water fisheries. Big game populations are expected to increase over the projection period. A sum across state agency big game projections indicates that an 11% gain in the number of big game animals can be expected if management activities planned by the state are actually implemented. Under a similar assumption, harvest levels of small game are expected to increase only 2% nationwide. The relatively small gain in the resource supply indicator for small game hunting is due primarily to declines in species associated with agricultural habitats, particularly northern bobwhite (see table 46). If habitat acquisition and habitat improvement activities scheduled in the North American Waterfowl Plan are accomplished, then hunter success (average number of birds bagged) is projected to increase by 17% (USDI Fish and Wildlife Service and Canadian Wildlife Service 1986a).

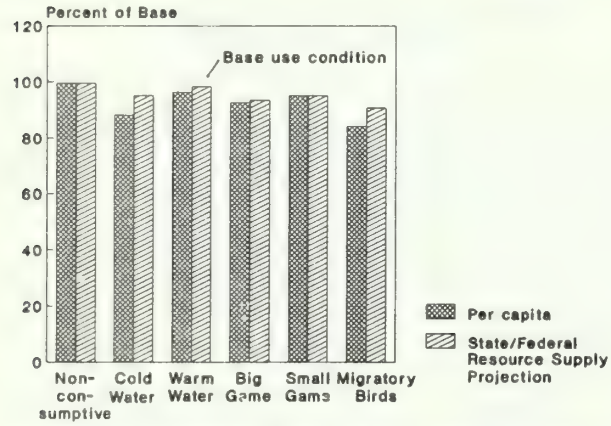


Figure 56.—Comparison of resource use projections under per capita availability and state/federal projection of future resource supplies as a percentage of base use conditions at 2040 (Base = 1980 = 100).

Recreational use projections under this set of resource supply indicators showed that even under assumed implementation of proposed management to improve future resource supplies, a relatively large component of unmet "demand" may remain for migratory game bird hunting (fig. 56). More moderate deviations from base level use, in rank order, were observed for big game hunting, coldwater fishing, and small game hunting. Nonconsumptive recreation and warmwater fishing deviated the least from base conditions.

SUMMARY

Comparison of wildlife and fish resource use and resource inventories is complicated by the fact that the number of people engaging in wildlife and fish recreation depends on the availability of wildlife and fish habitats and populations. A modeling approach that explicitly considered the relationship between recreational use levels and resource inventories provided a framework within which to compare the resource use and inventory projections. Coldwater fishing and migratory game bird hunting were the recreational activities most sensitive to changes in resource supply, followed by big game hunting, small game hunting, and warmwater fishing. The number of nonconsumptive recreationists was not affected by changes in the resource supply variable.

Increasing human populations imply that there will be less habitat and fewer animals per potential recreationist. A comparison of recreational use projections under two different resource supply situations—one assuming declining per capita resource availability, and another based on resource projections provided by state and federal agencies—indicate that migratory game bird hunting could potentially have the greatest proportion of "unmet demand." Big game hunting, coldwater fishing, and small game hunting had potentially moderate levels of unmet demand. The social, economic, and environmental implications of these comparisons, and of the use and inventory projections in general, are the subject of chapter 5.

CHAPTER 5: SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF WILDLIFE AND FISH INVENTORY AND USE PROJECTIONS

Wildlife and fish inventory and use projections have certain social, economic, and environmental implications. Social implications concern the behavior of individuals and groups and encompass cultural, societal, psychological, and physiological aspects. Economic implications concern consumption and production relationships, human community impacts, and monetary aspects of wildlife and fish resources. Environmental implications, arising out of concern for ecosystem health, are ultimately based on understanding the functioning of ecological systems.

Past evaluations of social, economic, and environmental implications of resource supplies and demands have tended to focus primarily on direct implications. However, direct implications stemming from resource use and management may represent only a small part of the cumulative impacts that can trace throughout social or ecological systems. Although people generally recognize that accounting for cumulative impacts is important, characterizing them can be especially difficult (Harris 1988). The complexity of social and environmental systems, as reflected in our limited understanding of how these systems respond when perturbed (human-induced and otherwise), hampers attempts to quantitatively address the implications. Consequently, this chapter largely synthesizes the literature on the potential impacts, direct and cumulative, as they relate to the uses and inventories of the nation's wildlife and fish resources.

SOCIAL IMPLICATIONS

Brown and Manfredo (1987) defined a social value typology that includes cultural, societal, psychological, and physiological values. These categories were used to discuss social implications. Although they are defined as separate classes of social value, they are not mutually exclusive.

Cultural Values

Different cultures, as defined by language, geographic boundary, and common historical and ethnic heritage (Kellert 1980), perceive and use wildlife and fish differently. Being able to use wildlife and fish resources in a manner consistent with those perceptions reinforces the social bond related to a person's cultural heritage.

Of the four social value categories, those dealing with cultural matters have been controversial regarding wildlife and fish resource use in recent years. For example, Native Americans' desire for increased jurisdiction over wildlife and fish resources to ensure preservation of their cultural heritage conflicts with the public trust doctrine (Steiner and Roberts 1987) in which state and federal governments control the management of wildlife and fish resources. The issue is an ongoing legal struggle concerning cultural values (Skoog 1979). Included in this conflict is the harvest of threatened and endangered species by Native Americans for subsistence and religious purposes (Bean 1986).

The general problem of illegal harvest also has roots in varying cultural values held for wildlife and fish resources. Disregard for harvest regulations can often be traced to traditional values held by certain cultural segments of society (see Anderson 1988).

Although individuals and cultural groups concede that wildlife and fish resources can only sustain a finite amount of consumptive use, determining and regulating appropriate resource distribution has been difficult (Cook 1982, Van Ballenberghe 1986). Failure to resolve the conflicts stemming from differences in cultural values could result in excessive use of wildlife and fish resources.

Societal Values

Societal values concern relationships among people and include family and social cohesion, social interaction, and community use values (Brown and Manfredo

1987, West 1986). Differences in societal values held by different cultures sharing a common resource have contributed to the difficulty in mediating resource use. Native Americans tender religious, subsistence, and other societal reasons for experiencing and consuming wildlife and fish resources. More recent immigrants to North America have societal values that include building personal character and social bonding among family and friends while participating in wildlife and fish related outdoor activities (Driver and Brown 1986). The implications of plural societal values are that wildlife and fish are important to different segments of the United States population in different ways. Despite variation in the public's interpretation of societal values, all interpretations share the basic similarity that family, community, and nation receive constructive influences from wildlife and fish.

Psychological Values

The psychological value of wildlife and fish is most obvious to the recreational user. The value of the opportunity to spend time in a natural environment observing or photographing wild animals, catching trout, or stalking big game is difficult to describe or quantify. Equally difficult to quantify is the value that a person derives from just knowing that species exist within a functioning ecosystem even though he or she may never use the resource directly (e.g., view or photograph that species). These experiences can be described in terms of the psychological value to an individual's personal well being. The cumulative implications stemming from this direct psychological benefit are broad and include increased productivity in the work place, enhanced creativity, enhanced cooperation, and increased respect for the law (Driver and Brown 1986, Ewert 1986). While the majority of individuals in the United States have positive psychological feelings toward wild animals, some people do dislike or find some wild animals to be threatening (Kellert 1980).

Physiological Values

Wildlife and fish resources can be of physiological benefit to individuals. Many recreational, commercial, and subsistence pursuits of wildlife and fish resources require a high degree of physical exertion resulting in fitness benefits to participants (Ewert 1986). Certain recreational experiences are perceived as a "competition" between human being and animal that involves mastering certain physical skills in order to observe, photograph, or harvest wild animals. Participants often express the belief that engaging in wildlife and fish recreation improves physical health through exercise, change of pace, and reduction of stress (Brown and Manfredo 1987).

Implications to Future Social Values

The wildlife and fish use and inventory projections reviewed in chapters 2, 3, and 4 raise concerns over the ability of wildlife and fish habitats and populations to meet future public demands for these resources. If resource inventories are not maintained and improved, then future social benefits currently attributable to wildlife and fish resources may decline. Wildlife and fish recreational activities could become overcrowded with an overall reduction in perceived societal, psychological, or physiological benefits as quality of experience is degraded.

Restricting future levels of use can facilitate balancing resource use with existing resource inventories. However, limiting the public's opportunity to enjoy wildlife and fish will not only infringe on the lifestyles of certain cultural segments of society but may also reduce or eliminate recreational outlets for which few complete substitutes exist (Krutilla and Fisher 1975). An alternative management option that at least maintains the social benefits attributable to wildlife and fish resources is to increase inventories to accommodate anticipated levels of use. The opportunities that exist to accomplish this, as perceived by state and federal managing agencies, are discussed in chapter 6.

ECONOMIC IMPLICATIONS

Economic implications are those that affect the way in which goods and services are produced, consumed, and exchanged in society. For wildlife and fish, economic implications are discussed as the effects on consumers (e.g., changes in "prices" paid for wildlife and fish outputs) and the effects on local economies and resource management budgets (e.g., changes in gross expenditures that ultimately affect businesses and resource managing agencies that support or provide wildlife and fish outputs).

Consumer or Price Effects

The capability to measure monetary value or prices varies with the way a resource is bought or consumed by the public. Unlike timber, mineral, and livestock resources which are generally bought and sold in the market place, wildlife and fish outputs are primarily produced and consumed outside traditionally organized markets. Exceptions to this generalization are found with commercial products such as fish and furs, and with fee-access for wildlife and fish recreation.

Commercial Products

Dockside salmon prices from 1979 to 1985 (measured in constant 1979 dollars) went from 77 cents/pound to

43 cents/pound, while total value (price x harvest) went from $413 million to $310 million—reductions of 44% and 26%, respectively (USDC National Oceanic and Atmospheric Administration, National Marine Fisheries Service 1979, 1985). Average pelt prices and total fur value received by trappers have also declined (Linscombe 1988). Between 1979 and 1985, the average real price per pelt received by trappers declined by 50%, while real total value declined by 75% (see figs. 26 and 29).

Predicting change in future dockside salmon and pelt prices is difficult; however, there are indications that scarcer resources could result in increased future prices for these commercial products. Weber (1986) discussed the concern for excessive salmon harvests and the need to restrict the future take to ensure future stocks are not depleted. If such restrictions are implemented, it seems likely that salmon prices will increase. Fur prices are variable due to changes in fashion. Assuming a constant demand for natural furs, then habitat losses, particularly wetland habitats, and potential restrictions in harvest from anti-trapping sentiments, are likely to limit pelt supplies resulting in future price increases.

Recreational Value of Wildlife and Fish

Apart from these commercial products, actual cash transactions for wildlife and fish outputs are relatively uncommon. In the absence of actual transactions, researchers have had to rely on indirect measures of wildlife and fish recreational values (Davis and Lim 1987).

Recreational and experiential uses of wildlife and fish have been measured in a variety of ways (Stoll 1986), but all methods involve estimates of prices consumers would be willing to pay under a market situation (Verburg et al. 1987). The two primary techniques used during the last 20 years for estimating recreational value of wildlife and fish are the "indirect actual market," or travel cost method, and the "direct hypothetical market," or the contingent value method (Peterson et al. n.d.). As described by Rosenthal et al. (1984), the travel cost method uses actual observations of travel costs and travel time from various origins to a particular recreation site, characteristics of that recreation site, and characteristics of consumers to indirectly estimate the price consumers may be willing to pay for a given recreational activity. Under the contingent value method, surveys are designed to directly elicit price estimates that consumers would be willing to pay for different types of recreational activities under a series of hypothetical situations.

In an effort to estimate the value of various wildlife and fish recreation activities, Sorg and Loomis (1984) summarized the best available information based on these indirect value estimation techniques. Brown and Hay (1987) subsequently estimated wildlife and fish recreational values from each state based on the 1980 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982) using the contingent value method. The wildlife and fish recreation values estimated from these two sources vary and reflect, in part, value differences associated with changes in location (site or state). Although the range in estimates is high, recreationists appear willing to pay the most for a day of big game hunting, followed by waterfowl hunting, small game hunting, coldwater fishing, and warmwater fishing (table 49).

Future Trends in Recreation Values

Given this review of current recreational value estimates, an important consideration for resource decision-making is whether future values will change, and in what direction. Peterson et al. (n.d.) described some factors that are responsible for changes in recreational economic values over time including: (1) changes in the real value of money, (2) changes in the real value of recreation due to supply and demand changes, (3) changes in methods and measurements, and (4) confusion over concepts and definitions. Factor 1 can be controlled by converting nominal values into real (net of inflation) dollars. Factors 3 and 4 affect the interpretation of historical value trends as evidence for future trends. While it is important to control for factors 1, 3, and 4, estimating change in value is most dependent on factor 2—namely, how will future supply (inventory) and demand (use) relationships for wildlife and fish resources influence future value?

In theory, changes in the balance between inventories and use would change wildlife and fish prices in the same fashion as though these resources were market goods. The results of the inventory and use comparisons reviewed in chapter 4 indicate that future inventories of wildlife and fish habitats and populations may not be capable of supporting the desired levels of recreational use. Under such a future, economic theory would project an increase in wildlife and fish recreation prices. In addition to resource scarcity, the lack of perfect substitutes for wildlife and fish recreation activities (Krutilla and Fisher 1975) also would suggest future increases in the economic value of wildlife and fish recreation.

Although theory suggests that prices will increase, the magnitude of the increase is unknown. Research on economic valuation of wildlife and fish resources has focused primarily on current estimates of value because no accepted or reliable method for predicting future values presently exists (Schweitzer and Stone 1987).

Despite the methodological problems associated with projecting future values, some data can be used to estimate the rate of value change based on trends from

Table 49.—Estimates and range of net economic values for various wildlife and fish recreational activities.

Activity	Activity day values in 1982 dollars		
	Sorg and Loomis Range	Brown and Hay Range	Brown and Hay Mean
	Dollars/day		
Big game hunting[1]	18–132	15–33	22
Small game hunting	16–43	—	—
Waterfowl hunting	16–85	9–26	15
Coldwater fishing[2]	9–38	8–33	14
Warmwater fishing	15–26	—	—

[1]*Brown and Hay estimates are for deer hunting only.*
[2]*Brown and Hay estimates are for trout fishing only.*
Note: All values were rounded to the nearest dollar.
Source: Brown and Hay (1987), Sorg and Loomis (1984).

the recent past. Peterson et al. (n.d.) and Sorg and Loomis (1984) were able to compare estimated values for coldwater fishing and deer hunting in three western states. Two time periods, at least 5 years apart, were used. Adjustments were made in the estimates to control for methodological differences, and comparisons were made within states to control for site differences. Based on these results, the real value of coldwater fishing appears to have increased from the late 1960's to the early 1980's at an average annual rate of 8.6% in Idaho and 5.5% in Arizona (table 50). The real value of deer hunting in Colorado increased at an average annual rate of 7.6% from 1974 to 1980.

Additional information on value trends of wildlife and fish recreation come from private access fees, ownership costs, and private lease fees for the primary purpose of fishing and hunting. Private fees and lease agreements provide previously unavailable transaction-based estimates of wildlife and fish values (Schenck et al. 1987). The demand for fee-hunting appears to be increasing (White 1987), and the projections reviewed in chapter 2 indicate that participation in fee-hunting could more than double by 2040 (see fig. 48). As demand has increased, the amount individual hunters and anglers have spent for private fees also has increased. The average annual increase from 1980 to 1985 (in constant 1980 dollars) varied from 7.1% for fishing to 12.3% for big game hunting (fig. 57) (USDI Fish and Wildlife Service 1988b; USDI Fish and Wildlife Service, and USDC Bureau of Census 1982). The increase in expenditures by persons who owned or leased land for wildlife and fish recreation was substantially greater. From 1980 to 1985, the average real amount an individual spent per year increased from $406 to $900 for an average annual increase of 24%. If the number of days spent hunting or fishing per individual under fee or lease situations has increased over this 5-year period, then the rates of increase reported here overestimate the increase on a per unit-day activity basis.

Local Economy and Management Budget Effects

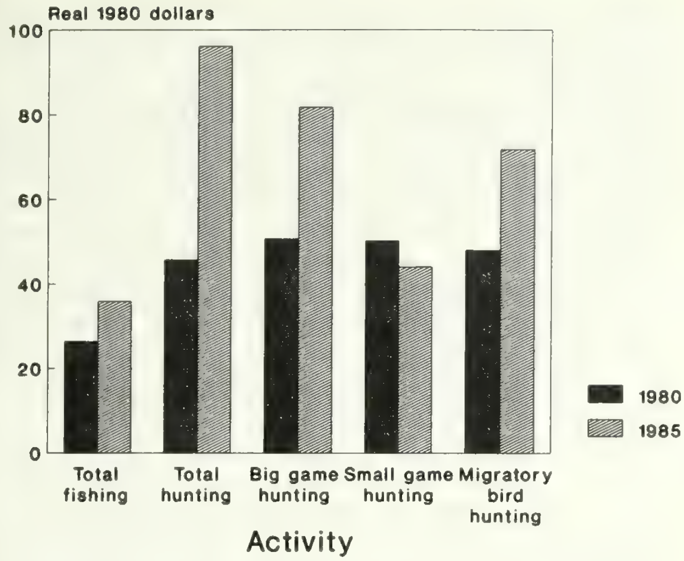
For commercial salmon and fur resources, harvest restrictions go beyond affecting the price. They also affect the income of fishers and trappers and income and employment in other businesses dependent on the harvests of these species (e.g., fish processing plants, furriers). Although the local economic implications associated with commercial harvests are important, particularly in regions such as the salmon-harvest areas of Alaska and the Northwest, more nationally widespread implications are associated with recreational aspects of wildlife and fish resources.

Historically, the role of economics in fisheries and wildlife management has been limited to estimating wildlife and fish recreation expenditures (Verburg et al. 1987). However, gross expenditures do not provide a satisfactory measure of economic value, but rather provide insight into local economic impacts (Bishop 1987). Expenditures also have a direct impact on state wildlife and fish management budgets.

Gross expenditures (in constant 1965 dollars) associated with hunting and fishing increased significantly from 1965 through 1980 for all activities except small game hunting and waterfowl hunting (figs. 58 and 59) (USDI Fish and Wildlife Service 1988b). After 1980, gross fishing expenditures continued to increase while hunting expenditures declined. Trends in expenditures for nonconsumptive recreational activities were only available since 1980 and indicate that trip-related

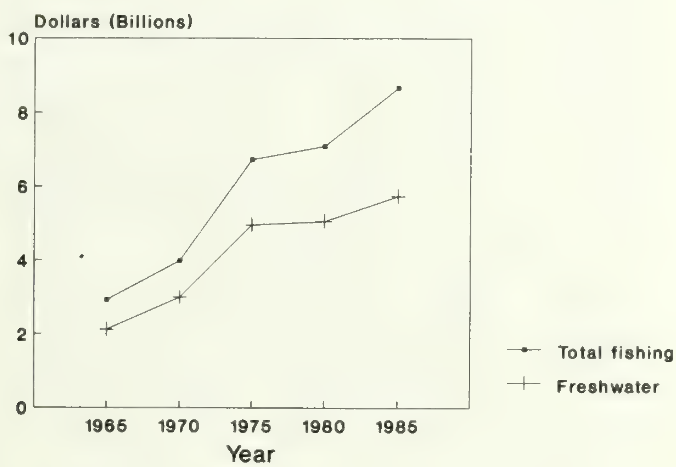
Table 50.—Recent historical trends in the value of coldwater fishing and deer hunting in three western states.

Activity	State	Study	Year	Activity day values (1982 dollars)
Coldwater fishing	Idaho	Gordon (1970)	1968	11.57
		Sorg et al. (1982)	1982	25.55
	Arizona	Martin et al. (1974)	1970	25.75
		Miller and Hay (1984)	1980	39.90
Deer hunting	Colorado	Miller (1980)	1974	18.40
		USDI Fish and Wildlife Service [n.d.]	1980	26.78



Source: USDI, Fish and Wildlife Service (1988b)

Figure 57.—Trend in private access fees (dollars per individual) for fishing and hunting.

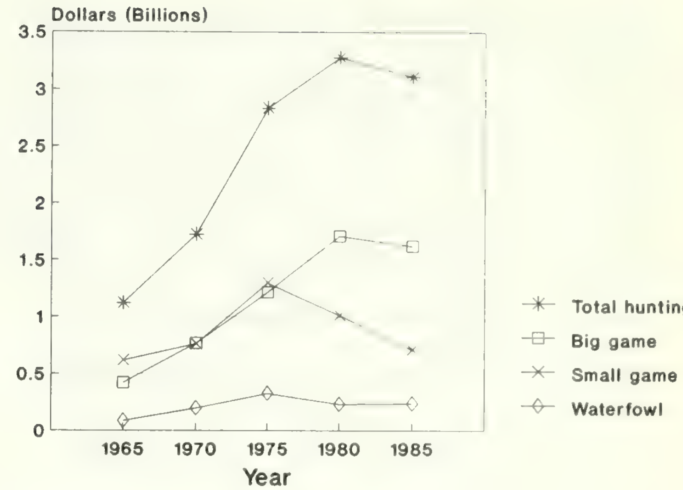


Source: USDI, Fish and Wildlife Service (1988b)

Figure 58.—Trends in gross expenditures for fishing from 1965–1985.

expenditures for primary nonresidential recreation declined from $1.58 billion in 1980 to $1.34 billion in 1985 (in constant 1965 dollars).

Given the recreation use projections in chapter 2, gross expenditures for fishing could increase in response to increased participation. Expenditures associated with primary nonresidential nonconsumptive trips could also increase since the number of recreationists engaging in this activity is expected to increase substantially (154%) by 2040. Hunting-related expenditures could decline as



Source: USDI, Fish and Wildlife Service (1988b)

Figure 59.—Trends in gross expenditures for hunting from 1965–1985.

total participation drops. If restrictive regulations are implemented to bring resource use in line with future resource inventories, then the expected increase in fishing expenditures would be dampened while the decline in hunting expenditures would be accentuated.

The effect of future declines in hunting-related expenditures goes beyond the direct impact on support businesses (e.g., those businesses providing lodging, food, equipment, etc.). An input-output model has been developed to track the expenditure effects throughout a regional economy (Alward and Palmer 1983). In a case study of how changes in big game hunting regulations affect the Colorado regional economy, Alward et al. (1984) showed that reduced expenditures not only affected direct support services but also affected wages and employment throughout the majority of industrial sectors comprising the regional economy. Although the greatest impact of reduced hunting expenditures would be to local areas that provide support services to this recreational activity, in the longer term substitute spending patterns would likely result in a restructuring of the regional economy rather than a total reduction in economic activity (Alward et al. 1984).

Declines in the number of hunters and declining expenditures also would impact state wildlife and fish agency budgets. The majority of funds available to state agencies are derived from hunters and anglers either through licence fees or excise taxes on equipment that are authorized under the Pittman-Robertson, Dingell-Johnson, and Wallop-Breaux Acts. State managers have expressed concern that revenues have not kept pace with inflation as many wildlife and fish agencies have experienced substantial declines in real revenue from license sales (Anderson et al. 1985). To maintain wildlife and fish programs, states have had to increase license fees or seek alternative funding sources.

Between 1979 and 1986, state agencies have witnessed shifts in the relative contributions from various funding sources (fig. 60). The most significant change in funding source was the increase from general state revenues. The proportional contribution of licence revenues has declined along with federal payments. The decline in the proportional contribution from federal payments would have been greater had it not been for the Wallop-Breaux program which tripled revenues into the Dingell-Johnson program (The Wildlife Conservation Fund of America 1987).

Anticipating further declines in hunter participation and the potential need for restricted access and use, state agencies will continue to face fiscal challenges and may have to restructure programs and funding sources (see for example Executive Task Force on the Future of Wildlife 1987, Van Vleck 1984). One potential opportunity for increasing state revenues concerns the nonconsumptive user. Although states have taken important steps towards integrating nongame programs into the management of wildlife and fish resources (45 states had recently allocated funds for nongame and endangered wildlife programs), the programs remain severely underfunded (Cerulean and Fosburgh 1986). In 1986, nongame programs represented less than 5% of the total budget in 29 states (Audubon Activist 1987). The nongame income tax check-off program, which is now in use in over 30 states, has witnessed significant declines as other checkoff options have been added to state income-tax forms (Shelton 1987). Harpman and Reuler (1985) concluded that although check-off programs were successful in the short-term, they should not be considered a stable, long-term source for funding nongame wildlife and fish programs.

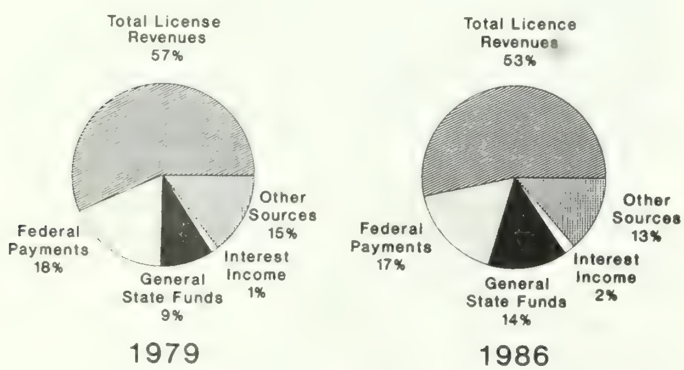
ENVIRONMENTAL IMPLICATIONS

Evaluating environmental implications of the wildlife and fish use and inventory projections requires understanding ecological systems and society's values for the mix of outputs that can be produced from the environment.

Society's values related to the environment have changed over time. The "exploitation era" of the 1800's was driven by strong commercial values (Poole and McCabe 1987). The abundance of natural resources on the North American continent appeared boundless. However, after a century of market hunting, trapping, clearing of forests for agriculture, fuel, and wood products, and plowing of native prairie, some Americans reconsidered the ability of the environment to support the rate of resource exploitation witnessed during the early 1900's (Kimball and Johnson 1978). As wildlife and fish resources became scarce, society's values changed. Notable declines, and in some cases the extinction, of wildlife and fish species stimulated a new emphasis on resource conservation. A series of protective laws was passed and wildlife and fish management became a profession entrusted with the responsibility of ensuring that wildlife and fish resources would be available to future generations.

Despite the growing support for wildlife and fish conservation and the mounting success stories attributable to wildlife and fish management, rising human populations will continue to encroach on remaining wildlife and fish habitat. In addition, continued demand for timber, domestic livestock, and crops will conflict, in many instances, with wildlife and fish resources. The challenge for future wildlife and fish management involves how to balance these multiple resource demands within the constraints defined by the environment. Failure to do so will result in unfavorable environmental alterations for wildlife and fish.

Demands for wildlife and fish resources are also expected to increase in the future, although the relative importance of various recreational activities is expected to change. Hunting-related demands are expected to become relatively less important than fishing and nonconsumptive recreation. Similarly, the American public increasingly pressures management agencies to maintain the integrity of ecological systems (Russell 1987) as evidenced in the passage of laws such as the Endangered Species Act and a number of other federal laws directed at maintaining habitat and species diversity (Bean 1977, Lund 1980). Consequently, more people demanding more wildlife and fish recreation opportunity indirectly demand more vigorous habitat and population management on a dwindling land base. The environmental implications of this assessment involve both habitat and species population considerations.



NOTE.--Other sources includes tax checkoffs

Source: Wildlife Management Institute. Outdoors News Bulletin 41(20).

Figure 60.—Sources of funds for fish and wildlife management in 1979 compared to 1986.

Implications for Wildlife and Fish Habitat

In recent history, the amount and quality of wildlife habitat has been changing. Additional changes are expected in the future, including a decline in forestland area, an increase in rangeland acres (expected under

the Conservation Reserve Program), and continued increases in urbanization. The "Swampbuster" and "Sodbuster" provisions of the 1985 Food Security Act could slow the rate at which wetlands are drained and highly erodible rangeland is converted to crop production. Acreage of open water habitats is projected to increase with farm pond and reservoir construction, and water quality is expected to improve as a result of the 1985 Food Security Act conservation programs and compliance with clean water legislation. In addition to these habitat composition changes (i.e., the amounts of land in various land-use types), future habitats will likely become more fragmented and insular in nature.

In this scenario, the composite national land area available for suitable wildlife habitat is likely to decline. This, coupled with a general increase in the number of wildlife and fish recreationists, will result in more crowded conditions.

Increased density of outdoor recreational use has been shown to cause vegetation trampling, changes in vegetation composition, soil compaction, and increased erosion (Cole 1986, Vaske et al. 1983), all resulting in degraded terrestrial and aquatic habitats. Washburne and Cole (1983) have reported that recreational use of wilderness areas (a portion of which is related to wildlife and fish use) has caused vegetation problems in 71% of all wilderness areas, soil impacts in 61%, and water pollution in 18%. Similar recreation impacts have also been noted in some riparian forests in the eastern United States (Cole and Marion 1988).

Although such impacts can be attributed to both consumptive and nonconsumptive activities, they appear to be especially common among nonconsumptive uses because of the significant increase in participants. Wilkes (1977) has stated that the term "nonconsumptive" has been detrimental to land-use planning because it projects a notion that such activities are benign in terms of environmental impacts, when in fact there are some very real and important impacts that must be addressed to preserve wildlife and fish habitat.

Implications for Wildlife and Fish Populations

As the amount and quality of habitats change, so will the distribution and abundance of wildlife and fish species. Wildlife and fish are critical components of ecosystems and perform various important functions such as pollination, dispersal and germination of seeds, soil and nutrient cycling processes, herbivory, predation, parasitism, and competition (Prescott-Allen and Prescott-Allen 1987). As these roles interact over time, they influence the distribution and abundance of species, the composition of functioning biotic communities, and thus ultimately determine the biotic diversity of animal communities (Harris 1988, Talbot 1987).

Based on the recent historical and future land base trends, faunas could become less diverse as human use of the land intensifies—a concern that is both national and global in scope (Norton 1986, Schonewald-Cox et al. 1983, Wilson 1988). Based on our current understanding, the effects of land-use intensification on biotic diversity can be grouped into four categories (Harris 1988): (1) loss of large, wide-ranging species, (2) loss of area-sensitive or interior species that require large tracts of contiguous habitat, (3) loss of genetic integrity, and (4) increased abundance of habitat generalists characteristic of disturbed environments. Ultimately, these four impacts result in the loss of species that give different communities their unique and distinguishing faunal characteristics while species already widespread and common among many regions are becoming more prominent.

Concern for declining diversity in natural communities is a concern for increasing species rarity and, in the extreme case, a concern for species extinctions. Species associated with old-growth or mature forests, native prairie, and wetlands seem destined to become rarer. Apart from these general perceptions, no one can predict with certainty how many additional species will become threatened or endangered with extinction. However, as land uses intensify, the potential exists for a higher proportion of the fauna to be threatened with extinction. In the United States, less than 10% of the vertebrate fauna is threatened or endangered. In West Germany, where intensive land use has a much longer history, 41% of the vertebrate fauna is endangered or threatened (The Conservation Foundation 1984).

Two direct consequences of increasing species rarity are prominent. First, genetic diversity declines which may ultimately affect the survival or recovery of a species. Loss of genetic diversity permanently eliminates opportunities to study how animals relate to their environments and their potential utility to humans (Ehrlich 1988, Schonewald-Cox 1986). A second consequence of rarity is that species' distributions become restricted to isolated areas. Although protection of special habitats has been important in the preservation of some species, Russell (1987) has expressed the view that the ecological legacy that the public wishes to leave to future generations is not one of open zoos in a few isolated areas of natural habitat, but one of healthy ecological systems in a common setting with human populations.

Increasing species rarity within a community is often accompanied by increasing abundance of common, widespread species with general habitat requirements. As was noted in chapter 1, downward trends in breeding nongame bird populations was accompanied by increases in species adapted to urban environments. In addition, Degraaf (1986) found that the habitat generalists dominating urban bird communities were often exotic species. Exotics are anthropogenically displaced species that have not been subjected to the coevolutionary processes important in the original formation of existing biotic communities and therefore violate the community's natural history.

Expression of reduced biotic diversity through dominance of a few abundant species can also lead to important economic costs associated with crop losses, reduction in timber regeneration, or livestock losses. In 1980, estimated losses of property to wildlife exceeded $8.6 million, and the Animal Damage Control Program (then under the Fish and Wildlife Service) spent $17.6 million in wildlife damage control efforts (USDI Fish and Wildlife Service 1981b). Overabundant wildlife usually generates concern for human health. Excessive populations of some furbearers has contributed to near epidemic levels of rabies throughout much of the East (Burridge et al. 1986), and increasing deer populations in the suburban Northeast are raising concern for the spread of Lyme disease.

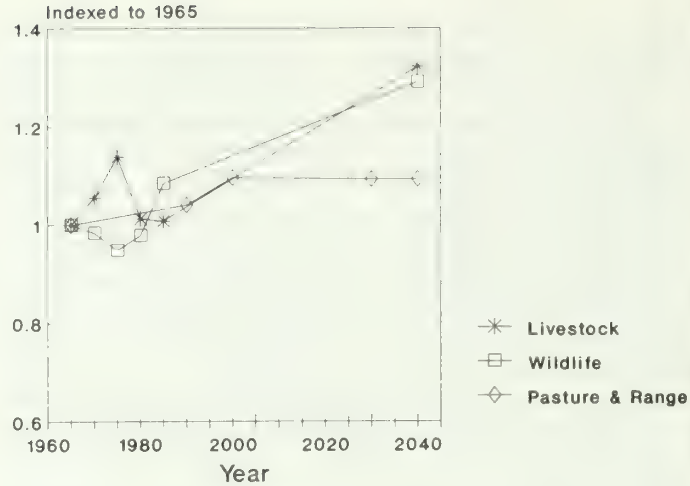
In addition to concerns for reduced biological diversity stemming from land-use intensification, use of wildlife and fish resources in excess of what inventories can support also has important implications to certain wildlife and fish populations. Despite declining dockside prices, commercial salmon harvests were the highest ever in 1985; the salmon population probably cannot sustain such harvest rates (Weber 1986). Illegal duck harvest in one Gulf coast state has been estimated to exceed four times the legal harvest, a situation an already declining duck population cannot withstand (Anderson 1988). Negative impacts associated with excessive use of wildlife and fish, however, are not restricted to consumptive activities. Nonconsumptive recreational activities have also been implicated in the displacement and even the death of wildlife (Cole 1986, MacArthur et al. 1982, Ream 1979, Stalmaster and Newman 1978, Vaske et al. 1983).

Environmental Implications from other Resource Demands

Clearly, public demands for resources other than wildlife and fish are an important consideration in identifying environmental implications. Demands for timber, range, and agricultural goods affect the kinds, amounts, and quality of wildlife and fish habitat. Increasing demands for timber products will likely have to be met with more intensive timber management (Haynes in press). Similarly, livestock forage demand is anticipated to increase which will require implementation of rangeland improvements to meet that demand (Joyce in press). The anticipated needs for more intensive management actions, in response to future demands for a single resource, carry with them multiple resource consequences (Hof and Baltic 1988, Risser et al. 1984).

The wildlife projections provided by state wildlife agencies did not explicitly consider these other resource demands on the land resource base and their resultant influence on wildlife and fish populations. Considering multiple demands for the resources jointly produced from any land type is necessary to avoid unanticipated resource management conflicts in the future.

As an example of the potential conflicts that can result, future wildlife demands for forage were compared to livestock demands for forage. Big game (deer, elk, and pronghorn) population projections from the state wildlife agencies were converted to AUM requirements and compared to projected livestock AUM's for the western United States (fig. 61). From 1985 to 2040, big game AUM's are projected to increase 19%; livestock AUM's are projected to increase 32%. Yet, the rangeland base is only expected to increase 10%. Although the degree of direct competition between wildlife and domestic livestock will depend on the species mix (wild and domestic) in any given area, the projections indicate that grazing pressure on western rangelands will intensify to a much greater degree than that implied by separate wildlife or livestock projections.



Source: Historical data: Livestock: USDA [various years], Joyce [in press], Wildlife: State Wildlife Agencies: 12 of 15 western states

Figure 61.—Indexed trends in livestock and wildlife AUM's and pasture- and rangeland area in the western United States.

SUMMARY

The wildlife and fish use and inventory projections imply certain economic, social, and environmental consequences that can occur if resource use and inventories are not balanced. The social values associated with fish and wildlife resources range from those held by Native Americans for subsistence and religious values, to rest, relaxation, and personal camaraderie resulting from recreational experiences dependent upon wildlife and fish. Declining future inventories or restricting opportunities to enjoy wildlife and fish not only infringes on the lifestyles of certain cultural segments of society, but also reduces or eliminates a recreational outlet for which few substitutes exist.

The economic costs associated with increasing scarcity of wildlife and fish resources can be grouped into direct effects on the "prices" paid by consumers and indirect effects on local economies and resource management budgets. Direct effects on consumers are most

obvious with commercial species such as salmon and furbearers. Concerns have been raised over the need to preserve minimum levels of salmon stocks, the loss of wetland habitats for furbearers, and a growing public sentiment against trapping. Under such restrictions in future supplies, consumers can expect to pay more for these products.

A similar situation holds for wildlife and fish recreation. Although not normally bought or sold under a market structure, wildlife and fish will "cost" recreationists more in the future. As habitat is lost or made unavailable to the recreating public, and as expanding human populations result in more crowded conditions, future recreationists may have to travel greater distances to find suitable recreation sites, or may have to pay access fees which may limit participation to the more affluent of society.

Restrictions on commercial harvests and projected declines in hunting also have indirect economic impacts on income, employment, and state resource management budgets. Employment and income impacts have important consequences in fishing communities such as coastal Alaska where other opportunities are limited. Declining hunter participation and associated expenditures could impact local areas that provide support services for this recreational activity. State wildlife and fish management agency budgets, for which funds are derived primarily from licence fees and excise taxes on equipment, would also be affected.

Growing human populations will continue to encroach on the remaining wildlife and fish habitat. In addition, continued demand for timber, livestock, water, and agricultural crops will conflict, in many instances, with wildlife and fish resources. The challenge for future wildlife and fish management involves how to balance these multiple resource demands within the constraints defined by the environment.

The more crowded conditions suggested by comparisons of future demands and supplies indicate that vegetation impacts, soil compaction, water pollution, disturbance of wildlife, and other environmental problems will increase. Although such impacts can be attributed to all forms of wildlife and fish recreation, these impacts are of particular concern with the fishing and nonconsumptive recreating public because of the magnitude of projected increases.

As the amount and quality of habitats change, so will the distribution and abundance of wildlife and fish. The growing pressures on wildlife and fish are likely to be especially significant for endangered and threatened species and those species with the potential to become so. As the biotic diversity of the nation's wildlife and fish communities diminishes, the nation loses part of its natural heritage and future options for study and other interactions.

The specific resource management issues that stem from the social, economic, and environmental impacts discussed here were identified by state and federal resource managers. Chapter 6 summarizes these issues and reviews the management opportunities that exist to address them.

CHAPTER 6: MANAGEMENT ISSUES AND OPPORTUNITIES FOR IMPROVING THE WILDLIFE AND FISH RESOURCE SITUATION

Wildlife and fish resources were once perceived to have unlimited capacity to support human use (Kimball and Johnson 1978, Schmidt 1978, Taber 1983). With unregulated exploitation of wild populations and habitats, the fact became apparent that conservation of the nation's flora and fauna would require management—willful and informed manipulation by human beings.

Regulating the exploitation of wildlife and fish resources was the first and most important conservation concern in the early history of wildlife management. However, simply regulating the take of game populations failed to control the decline of many animal populations. Growing human populations and the attendant intensified land-use has reduced the availability of suitable wildlife and fish habitats. Human beings have expanded their niche at the expense of other animals (Brokaw 1978). The implication is that conservation of wildlife and fish resources, in light of what are often conflicting human demands for natural resources, will require improved wildlife and fish management (Taber 1983).

WILDLIFE AND FISH MANAGEMENT ISSUES

Management issues were identified by state agencies responsible for wildlife and fish management, National Forest System biologists, and Bureau of Land Management biologists. These agencies provided a priority listing of the most important management issues for each of eight species groups. These groups included big game, small game, waterfowl, anadromous fish, resident coldwater fish, resident warmwater fish, nongame, and threatened and endangered species. Within each species group, management issues were split into four categories: habitat, population, user, and planning-related issues.

Issues Perceived by the States

States are entrusted with the stewardship of wildlife and fish resources; and as resource trustees, they have a major responsibility for wildlife and fish management. Federal agencies also have wildlife and fish stewardship obligations for migratory birds, marine animals, and for animals and habitats on federal lands. However, the federal stewardship role has, in general, been one of cooperation with states to facilitate their management goals (Lund 1980). Under the state ownership doctrine, the state wildlife agencies must hold a comprehensive view of wildlife and fish resources within its boundaries. Consequently, the state biologists' perceptions of the important wildlife and fish management issues presumably represent a composite across all land ownerships.

Information provided by state agencies was summarized by examining the mean priority ranking (where "1" represents an issue of greatest concern) across states and the frequency with which an issue was cited. The overall importance of an issue was assumed to be a function of its mean rank and its frequency. An index of relative importance was calculated using the following method:

1. Divide the mean rank of each management issue by the frequency. The management issue with the lowest quotient is interpreted to be the most important.
2. Calculate an "index of importance" for each issue relative to the most important management issue. This was accomplished by dividing the quotient of the most important issue identified in step one into the quotient associated with each management issue. Thus, the most important issue has an index of importance equal to 1.0.
3. Sort the scores of relative importance calculated in step two in ascending order. The result is a list of management issues from the most important to the least important.

Summary Across Species Groups

State wildlife and fish biologists identified 30 management issues (table 51). At the national level, seven issues appeared to be particularly important to current resource managers. These issues are evenly distributed across the major management categories of habitat, population, user, and planning.

Habitat ranked as the most important management issue identified. Habitat area loss and habitat quality degradation were the two most frequently cited problems and were the greatest concern of all identified management issues. As human populations expand and land uses intensify, the amount and quality of wildlife and fish habitats suffer. Habitat is in many ways the most fundamental management issue now confronting state agencies, for landscapes lacking in suitable wildlife and fish habitats will no longer support animal populations to monitor or uses to regulate. Although states hold wildlife and fish resources in trust, they have no habitat management authority on private lands unless landowners request assistance or enter into habitat management agreements.

The third and fourth most critical management issues concerned aspects of wildlife and fish populations. Inventory information on wildlife occurrence, population

Table 51.—Management issues for all species groups identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

	National			North			South			Rocky Mountain			Pacific Coast		
Management issue	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat loss	1.0	142	1.6	1.0	54	1.6	1.0	38	1.7	1.0	42	1.6	1.5	8	1.6
Habitat degradation	1.6	117	2.1	1.9	37	2.1	2.4	24	2.6	1.1	45	1.9	1.0	11	1.5
Lack population information	2.0	98	2.2	1.4	43	1.8	3.7	15	2.5	2.1	32	2.5	2.6	8	2.8
Population low/ unoccupied habitat	3.3	57	2.1	4.0	21	2.5	2.6	14	1.6	2.8	18	1.9	4.2	4	2.3
Restricted access	3.3	71	2.6	3.1	29	2.7	4.3	15	2.9	3.1	22	2.6	2.6	5	1.8
Lack info. on public/ public support	3.3	70	2.6	3.0	29	2.6	4.5	13	2.6	2.5	26	2.5	11.0	2	3.0
Multiple resource conflicts	3.7	60	2.5	2.5	28	2.1	4.7	11	2.3	5.4	17	3.5	2.4	4	1.3
Lack habitat info. (requirements/ inventory)	5.3	37	2.2	4.2	12	1.5	9.5	8	3.4	3.9	15	2.2	5.5	2	1.5
Excessive demand	6.3	42	3.0	4.6	22	3.0	9.6	7	3.0	6.1	13	3.0	.	.	.
Pollution	7.0	33	2.6	4.4	19	2.5	7.5	6	2.0	12.4	7	3.3	22.0	1	3.0
Limited resource planning	9.2	25	2.6	8.8	10	2.6	6.1	7	1.9	12.8	7	3.4	7.3	1	1.0
Population too high	12.2	8	1.1	6.8	5	1.0	16.8	2	1.5	26.3	1	1.0	.	.	.
Habitat management constrained/ineffective	12.4	20	2.8	67.5	1	2.0	7.0	9	2.8	8.8	9	3.0	7.3	1	1.0
Increased human populations	13.0	15	2.2	30.4	3	2.7	4.2	8	1.5	35.0	3	4.0	7.3	1	1.0
Enforcement of regs./inadequate regs.	14.5	19	3.1	12.2	10	3.6	13.4	5	3.0	17.5	3	2.0	7.3	1	1.0
Interspecific competition	15.1	17	2.9	59.1	2	3.5	33.5	2	3.0	11.8	8	3.5	2.1	5	1.4
Barriers to migration	17.8	8	1.6	9.5	5	1.4	27.9	2	2.5	26.3	1	1.0	.	.	.
Hunter ethics	18.9	15	3.2	25.3	4	3.0	50.3	2	4.5	12.4	7	3.3	7.3	2	2.0
Insufficient/inadequate harvest	23.7	9	2.4	50.6	2	3.0	8.4	4	1.5	39.4	2	3.0	29.3	1	4.0
Excessive harvest	24.1	7	1.9	25.9	3	2.3	9.7	3	1.3	52.5	1	2.0	.	.	.
Illegal harvest	25.3	13	3.7	23.6	4	2.8	22.4	4	4.0	26.3	4	4.0	36.7	1	5.0
Declining/low demand	29.3	10	3.3	59.1	2	3.5	33.5	2	3.0	17.9	5	3.4	22.0	1	3.0
Population distribution inadequate	33.0	7	2.6	25.3	2	1.5	27.9	2	2.5	52.5	2	4.0	14.7	1	2.0
Habitat diversity loss	39.9	4	1.8	22.5	3	2.0	22.4	1	1.0	.	.	.	.	.	.
Disease/parasites	53.3	5	3.0	59.1	2	3.5	.	.	.	45.9	2	3.5	7.3	1	1.0
Other population-related problems	53.3	5	3.0	33.8	3	3.0	.	.	.	39.4	2	3.0	.	.	.
Political constraints	68.0	3	2.3	67.5	1	2.0	.	.	.	32.8	2	2.5	.	.	.
Predation	79.9	3	2.7	.	.	.	.	.	.	23.6	3	2.7	.	.	.
Excessive access	155.3	2	3.5	.	.	.	.	.	.	78.8	1	3.0	29.3	1	4.0
Other habitat-related problems	266.3	1	3.0	.	.	.	67.1	1	3.0	.	.	.	.	.	.

Note: f = Frequency.

levels, and population parameters (e.g., natality and mortality rates) are difficult to obtain. Considerable research has been devoted to developing both theory and techniques for monitoring wildlife and fish populations; however, for large scale assessments there is a need for practical techniques that provide information at the regional and state levels of geographic resolution (Hawkes et al. 1983, Moyle et al. 1979, Sanderson et al. 1979). Although the importance of population inventory deficiencies varies across species groups, it represents the third most important management issue when summarized across all species groups. The fourth most important management issue involved low population levels. In some cases, this management issue is ultimately related to low habitat quality. In other cases, wildlife and fish population levels have not reached the carrying capacity of the habitat, or suitable habitat remains unoccupied.

Issues related to resource use are another important component of wildlife and fish management. Regulating the number of consumptive users, hunting and fishing season lengths, and harvest quotas are important responsibilities of state agencies. The amount of forest and rangeland environments has not changed dramatically in the recent past, nor is it expected to change dramatically in the future (Bones in press). However, the availability of land for wildlife and fish recreation has become an important concern. Although certainly related to habitat loss, restricted access is an equally important factor contributing to the declining availability of land for recreation. This is of particular interest in areas of the country with little public land. The problem is not restricted to these areas since access to public land is often controlled by private landowners and trespass privileges are not always granted.

Another important issue related to use of wildlife and fish resources concerns the lack of comprehensive information on attitudes about wildlife and fish resources and their management. There are two points of reference in this management issue. State agencies lack information on the public attitudes and values held for wildlife and fish resources, and the public lacks information on the justification for specific management actions implemented by state agencies. Ultimately, both translate into a concern for public support of wildlife and fish management. As summarized by Peek (1986), wildlife managers need more than ever to ensure public understanding of how proposed management activities will benefit the resource, or run the risk of declining support stemming from a misinformed public.

Because the nation faces increased competition for resources produced from a finite land base, multiple resource conflicts are an important concern of state wildlife and fish managing agencies. More intensive agricultural practices and timber management, competition with livestock, mineral development, water withdrawals for consumption or irrigation, and wildlife damage to crops all serve to illustrate that wildlife and fish management is much more complicated than direct habitat improvement, manipulating animal populations, or regulating use. Resource planning that acknowledges and addresses wildlife and fish in a multiple resource context is critical if future supplies of wildlife and fish habitats and populations are going to be available to commercial, subsistence, and recreational user groups. Although widely recognized as an important planning objective, the integration of wildlife and fish programs into other land management activities remains a notable shortcoming (Peek 1986).

These major issues tended to be consistent across each assessment region though the rank order varied (table 51). There were only a few cases where the most important regional issues were absent from the national list. In the South, a general concern for increasing human populations due to increased migration to the sunbelt states was raised as an important issue. In the Rocky Mountains, a lack of habitat inventory information was viewed as a constraint on effective wildlife management. Interspecific competition was the third most important issue in the Pacific Coast, owing to unique problems on the Hawaiian archipelago with exotics.

The summarization across all species groups provides a general picture of the states' perception of important wildlife and fish management issues. However, important issues specific to individual species categories are lost in such a comprehensive summary.

Big Game

A total of 20 big game management issues were identified by state wildlife and fish agencies. Many are the same as those described by Wolfe (1978) and the previous wildlife and fish assessment (USDA Forest Service 1981). The highest ranked big game management issues included habitat loss, habitat degradation, restricted access for users, excessive game populations, multiresource conflicts, and deficient data to quantify wildlife and fish populations (table 52).

The recent historical picture documented in chapter 1 indicates that issues related to big game management exist at several scales. For example, the loss of forestland throughout the nation will, in general, reduce the habitat available to forest big game species. More specifically, the loss of winter range or thermal cover in the North and West could make the habitat remaining for big game species less useful. Human development on winter range and domestic livestock conflicts were important habitat related concerns in the West. In the North, the absence of forest disturbance was an important habitat management issue. Farming and timber harvesting have replaced, in part, the natural role of fire in disrupting and retarding forest succession (Wolfe 1978). However, forest disturbance factors have not kept pace with the forest succession resulting in a deterioration of big game habitat quality in the North.

An issue unique to big game management was that population levels of some species were considered excessive. This was largely an issue related to white-tailed deer in some of the eastern and midwestern states. Although excessive big game populations were not frequently cited, in those states where it was a problem it was the most important big game management issue.

Table 52.—Management issues for big game identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

Management issue	National			North			South			Rocky Mountain			Pacific Coast		
	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat loss	1.0	21	1.6	1.0	9	1.8	1.0	5	1.6	1.3	6	1.5	1.3	1	1.0
Habitat degradation	1.6	16	1.9	2.9	4	2.3	3.9	2	2.5	1.0	8	1.6	1.0	2	1.5
Restricted access	2.0	17	2.6	2.1	6	2.5	1.5	5	2.4	3.2	5	3.2	1.3	1	1.0
Population too high	2.1	7	1.1	1.3	4	1.0	2.3	2	1.5	5.0	1	1.0	.		.
Multiple resource conflicts	2.3	18	3.1	1.9	8	3.0	3.4	3	3.3	2.8	6	3.3	2.7	1	2.0
Lack population information	2.4	14	2.6	1.7	6	2.0	.	.	.	2.3	6	2.8	2.3	2	3.5
Insufficient/inadequate harvest	3.6	7	1.9	7.5	2	3.0	1.2	4	1.5	5.0	1	1.0	.	.	.
Population low/unoccupied habitat	3.8	8	2.3	3.8	3	2.3	2.4	3	2.3	5.0	1	1.0	4.0	1	3.0
Lack info. on public/public support	4.9	10	3.7	2.3	8	3.6	15.6	1	5.0	15.0	1	3.0	.	.	.
Illegal harvest	5.5	9	3.8	5.0	3	3.0	4.2	3	4.0	10.0	2	4.0	6.7	1	5.0
Hunter ethics	6.1	6	2.8	5.0	1	1.0	.	.	.	4.4	4	3.5	2.7	1	2.0
Excessive demand	7.9	5	3.0	8.8	2	3.5	9.4	1	3.0	6.3	2	2.5	.	.	.
Increased human populations	9.8	2	1.5	10.0	1	2.0	3.1	1	1.0	.	.	.	.	.	.
Enforcement of regs./inadequate regs.	13.1	1	1.0	.	.	.	.	.	.	.	.	.	1.3	1	1.0
Political constraints	13.1	1	1.0	.	.	.	.	.	.	5.0	1	1.0	.	.	.
Habitat management constrained/ineffective	19.7	2	3.0	.	.	.	4.7	2	3.0	.	.	.	.	.	.
Lack habitat info. (requirements/inventory)	23.0	2	3.5	.	.	.	15.6	1	5.0	10.0	1	2.0	.	.	.
Declining/low demand	23.0	2	3.5	20.0	1	4.0	.	.	.	15.0	1	3.0	.	.	.
Excessive access	23.0	2	3.5	.	.	.	.	.	.	15.0	1	3.0	5.3	1	4.0
Interspecific competition	26.3	2	4.0	.	.	.	9.4	1	3.0	25.0	1	5.0	.	.	.

Note: f = frequency.

Restricted access for users was a contributing factor to the excessive population issue since it constrains meeting harvest objectives. Restricted access is also a concern since it prevents satisfaction of the user demand for the resource. The availability of big game hunting recreation on public lands becomes an increasingly important consideration as access is restricted on private lands. The southeastern states were particularly concerned about access to big game ranges.

Alteration of habitat resulting from land use changes, logging or the lack of logging activities, developed recreation areas, disturbance from off-road vehicles, livestock management, and crop damage by big game species were the basis for the multiple resource conflict issue.

Small Game

A majority of the most important issues related to small game management were the same as for big game; however, the order of importance was different. From the states' perspectives, the critical management issues were habitat area loss, restricted access, habitat degradation, multiple resource conflicts, and low populations or unoccupied habitat (table 53).

A prominent small game management issue was low populations of species associated with agricultural habitats. However, inadequate populations of small game can not be discussed independently from habitat degradation and loss. Many small game species require a close juxtaposition of life requisites. Consequently, the trend toward more intensive agriculture (see chapter 1) has reduced the availability of suitable small game habitats. Fortunately, most small game species have a high reproductive potential and can recover quickly from low population levels when suitable habitat becomes available.

Much of the small game resource is produced on private land and related to agriculture forest-range interfaces or early successional forest habitats. Even where quality habitat exists, restricted access to private lands has resulted in populations that are unavailable to the recreating public. This is particularly important to small game recreation since nearly 75% of all small game hunting occurred on private lands in 1980 (USDI Fish and Wildlife Service, and USDC Bureau of Census 1982).

The relative rankings of small game management issues within assessment regions deviated little from the national level. Concerns for habitat loss, habitat degradation, and multiple resource conflicts were well distributed across the country and tended to maintain their relative rankings across regions. Restricted access was generally ranked as a more important issue and was a more wide-spread concern than low population levels. Low small game populations were a prevalent concern in the South.

Waterfowl

Twenty-five issues were identified to be of concern regarding waterfowl management (table 54). Long-distance migration is a distinctive feature of this group. Consequently, management issues raised by individual agencies many times spanned state and national boundaries.

Loss of wetland habitats was clearly the most important national and regional management issue related to this species group. Wetland habitat degradation and isolation resulting from intensive use of surrounding upland environments was also one of the top concerns raised by the state agencies. As reviewed in chapter 1, the major factor contributing to habitat loss and degradation was agricultural development. Although ducks will make use of agricultural grains, they prefer natural

Table 53.—Management issues for small game identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

Management issue	National			North			South			Rocky Mountain			Pacific Coast		
	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat loss	1.0	25	1.2	1.0	11	1.2	1.0	7	1.4	1.0	6	1.2	1.3	1	1.0
Restricted access	2.5	19	2.3	2.6	8	2.3	3.5	4	2.8	2.4	5	2.4	1.0	2	1.5
Habitat degradation	3.2	15	2.3	5.3	4	2.3	3.8	4	3.0	1.7	6	2.0	1.3	1	1.0
Multiple resource conflicts	4.3	12	2.5	5.7	4	2.5	2.8	3	1.7	4.4	4	3.5	1.3	1	1.0
Population low/unoccupied habitat	4.6	9	2.0	7.0	3	2.3	2.2	3	1.3	3.8	2	1.5	5.3	1	4.0
Lack population information	6.0	9	2.6	4.6	4	2.0	.	.	.	5.0	3	3.0	2.0	2	3.0
Lack info. on public/public support	6.3	7	2.1	8.3	3	2.7	.	.	.	2.3	4	1.8	.	.	.
Increased human populations	6.9	6	2.0	.	.	.	2.2	3	1.3	8.8	2	3.5	1.3	1	1.0
Hunter ethics	11.7	5	2.8	27.5	1	3.0	20.0	1	4.0	6.3	2	2.5	2.7	1	2.0
Lack habitat info. (requirements/inventory)	12.5	5	3.0	9.2	2	2.0	8.8	2	3.5	20.0	1	4.0	.	.	.
Habitat management constrained/ineffective	15.6	4	3.0	.	.	.	.	.	.	3.8	4	3.0	.	.	.
Habitat diversity loss	15.6	2	1.5	6.9	2	1.5	.	.	.	.	.	.	.	.	.
Excessive demand	17.5	5	4.2	8.7	4	3.8	.	.	.	30.0	1	6.0	.	.	.
Declining/low demand	31.3	2	3.0	.	.	.	7.5	2	3.0	.	.	.	.	.	.
Insufficient/inadequate harvest	46.9	2	4.5	.	.	.	.	.	.	25.0	1	5.0	5.3	1	4.0
Limited resource planning	62.5	1	3.0	27.5	1	3.0	.	.	.	.	.	.	.	.	.
Predation	62.5	1	3.0	.	.	.	.	.	.	15.0	1	3.0	.	.	.

Note: f = frequency.

Table 54.—Management issues for waterfowl identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

Management issue	National			North			South			Rocky Mountain			Pacific Coast		
	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat loss	1.0	27	1.4	1.0	12	1.2	1.0	6	1.5	1.0	7	1.7	1	2	1
Multiple resource conflicts	3.2	11	1.8	2.0	6	1.2	12.0	1	3.0	8.2	2	4.0	1	2	1
Population low/unoccupied habitat	3.7	10	1.9	8.3	4	3.3	1.3	3	1.0	1.4	3	1.0	.	.	.
Habitat degradation	4.4	11	2.5	10.0	2	2.0	3.8	4	3.8	1.9	4	1.8	2	1	1
Restricted access	5.0	12	3.1	11.0	3	3.3	4.4	3	3.3	2.3	5	2.8	6	1	3
Lack population information	6.3	8	2.6	5.7	3	1.7	6.0	2	3.0	6.2	2	3.0	8	1	4
Excessive demand	7.1	9	3.3	20.0	2	4.0	2.6	5	3.2	6.2	2	3.0	.	.	.
Population distribution inadequate	7.7	5	2.0	7.5	2	1.5	5.0	2	2.5	.	.	.	4	1	2
Habitat management constrained/ineffective	8.5	5	2.2	20.0	1	2.0	12.0	1	3.0	5.1	2	2.5	2	1	1
Pollution	9.2	8	3.8	12.3	3	3.7	5.0	2	2.5	6.5	3	4.7	.	.	.
Lack info. on public/public support	13.5	4	2.8	12.5	2	2.5	.	.	.	6.2	2	3.0	.	.	.
Population too high	19.3	1	1.0	10.0	1	1.0	.	.	.	.	.	.	.	.	.
Increased human populations	19.3	2	2.0	.	.	.	4.0	2	2.0	.	.	.	.	.	.
Interspecific competition	21.2	3	3.3	50.0	1	5.0	.	.	.	12.4	1	3.0	4	1	2
Predation	24.1	2	2.5	.	.	.	.	.	.	5.1	2	2.5	.	.	.
Excessive harvest	28.9	2	3.0	15.0	2	3.0	.	.	.	.	.	.	.	.	.
Political constraints	28.9	2	3.0	20.0	1	2.0	.	.	.	16.5	1	4.0	.	.	.
Illegal harvest	33.8	2	3.5	.	.	.	16.0	1	4.0	12.4	1	3.0	.	.	.
Declining/low demand	33.8	2	3.5	.	.	.	.	.	.	16.5	1	4.0	6	1	3
Limited resource planning	38.6	2	4.0	40.0	1	4.0	.	.	.	16.5	1	4.0	.	.	.
Hunter ethics	43.4	2	4.5	.	.	.	20.0	1	5.0	16.5	1	4.0	.	.	.
Habitat diversity loss	57.9	1	3.0	30.0	1	3.0	.	.	.	.	.	.	.	.	.
Other population-related problems	57.9	1	3.0	.	.	.	.	.	.	12.4	1	3.0	.	.	.
Lack information (requirements/inventory)	77.1	1	4.0	.	.	.	16.0	1	4.0	.	.	.	.	.	.
Enforcement of regs./inadequate regs.	96.4	1	5.0	.	.	.	20.0	1	5.0	.	.	.	.	.	.

Note: f = frequency.

foods that grow in or near water (Bellrose 1976). Geese, on the other hand, are more adaptable and will feed readily on green vegetation or waste grains on upland sites (USDI Fish and Wildlife Service 1987a). Agricultural crops are the mainstay of migrating and wintering goose populations (Bellrose 1976). Based on these differing habitats, state concerns for habitat loss and low waterfowl populations were, in general, related to ducks rather than geese.

Because of the close association between waterfowl habitat and agriculture development, multiple resource conflicts also ranked as an important waterfowl management issue. Multiple resource conflicts, however, are not restricted to agricultural land uses but also include timber, range, and water management interactions.

Another correlate of wetlands in agricultural environments is concern over the availability of the resource to the recreating public. Nearly three-quarters of the

nation's remaining wetland habitat is privately owned and restricted access for waterfowl hunters is a problem cited in all regions of the country. Although hunter lease agreements may provide incentive to landowners to provide access and preserve wetland habitats, participation in waterfowl hunting may become limited to that clientele who can afford to pay for the privilege to hunt on private land. In a survey asking state agencies to rank those species most important in hunter lease arrangements, Wiggers and Rootes (1987) found that waterfowl was the most frequently cited species category, followed by white-tailed deer, wild turkey, and bobwhite quail.

Two issues that were of regional importance, primarily in the East, were inadequate waterfowl population distribution and the use of lead shot. Although of low national priority, some southern states are concerned that waterfowl populations are being held farther north during the fall migration which effectively limits the availability of waterfowl for southern hunters. This alteration of migration chronology has been documented for both snow and Canada geese in response to agricultural development and associated reservoir construction in the Midwest (Batemen et al. 1988, Simpson 1988). Lead poisoning in ducks that ingest lead shotgun pellets and secondary poisoning in some raptors that feed on those ducks has been documented (USDI Fish and Wildlife Service 1987a). However, with total conversion to nontoxic steel shot planned by 1991, the lead shot issue should only continue into the short-term.

Anadromous Fish

The most important management concerns related to the anadromous fishery result from the migratory habits of the species comprising this category. These species mature in the ocean and migrate to spawning areas in headwater streams. The number one management issue identified by the states was dams that exist in the east, west, and Great Lakes coastal rivers that serve as migration barriers (table 55). Originally, fisheries biologists thought that providing upstream passage for adults would be sufficient to maintain anadromous fishery stocks. However, research has shown that fish can suffer high mortality as they encounter dams during juvenile downstream migration (Northwest Power Planning Council 1987). The concern associated with juvenile migration to the ocean is further confounded by water storage facilities designed to increase the generating capacity of mainstem hydroelectric dams. These storage facilities decrease water flows over spillways and force passage through the turbines where mortality can be as high as 15% to 20% per dam (Phinney 1986). Consequently, the cumulative impacts associated with passage through multiple hydroelectric facilities can be high, particularly during low flow years (Phinney 1986).

Although considerable progress has been made in the installation of fishways, additional installations, and improved operation of fishways formed the basis for concern with returning adult spawners. Inadequate flows at fishways have resulted in ineffective use of these facilities by migrating salmon and steelhead (Northwest Power Planning Council 1987).

Additional management issues of primary concern included: (1) habitat degradation associated with sedimentation, and the loss of within stream and streamside cover; (2) low populations of certain species including the Atlantic salmon and striped bass; (3) both point and nonpoint sources of pollution; (4) multiple resource conflicts with agricultural development, increased sediment and loss of streamside cover associated with timber harvesting and road development, and livestock conflicts associated with grazing on riparian areas; and (5) excessive harvest. Continual excessive harvests could have the greatest long-term effect on the anadromous fishery but also have the best opportunity for short-term change.

Resident Coldwater Fish

Primary concerns for coldwater fishery management included the loss and degradation of habitat (table 56). Fewer miles of coldwater streams resulting from

Table 55.—Management issues for anadromous fish identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

	National			North			South			Rocky Mountain			Pacific Coast		
Management issue	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Barriers to migration	1.0	8	1.6	1.0	5	1.4	2.5	2	2.5	1	1	1	.	.	.
Habitat degradation	1.2	8	1.9	1.3	5	1.8	2.0	1	1.0	4	1	4	1	1	1
Population low/unoccupied habitat	2.5	4	2.0	5.4	2	3.0	1.0	2	1.0	.	.	.	.	.	.
Pollution	3.3	3	2.0	3.6	2	2.0	4.0	1	2.0	.	.	.	.	.	.
Multiple resource conflicts	3.4	5	3.4	3.6	3	3.0	6.0	1	3.0	5	1	5	.	.	.
Excessive harvest	3.8	2	1.5	.	.	.	2.0	1	1.0	2	1	2	.	.	.
Habitat loss	5.0	2	2.0	3.6	2	2.0	.	.	.	.	.	.	.	.	.
Lack population information	5.0	1	1.0	3.6	1	1.0	.	.	.	.	.	.	.	.	.
Excessive demand	5.0	2	2.0	3.6	2	2.0	.	.	.	.	.	.	.	.	.
Enforcement of regs./inadequate regs.	7.5	2	3.0	14.3	1	4.0	4.0	1	2.0	.	.	.	.	.	.
Other population-related problems	7.5	2	3.0	10.7	1	3.0	.	.	.	3	1	3	.	.	.
Disease/parasites	15.0	1	3.0	10.7	1	3.0	.	.	.	.	.	.	.	.	.

Note: f = frequency.

Table 56.—Management issues for resident coldwater fish identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

Management issue	National			North			South			Rocky Mountain			Pacific Coast		
	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat degradation	1.0	18	1.4	1.0	7	1.3	1.2	2	1.0	1.2	7	1.7	1.0	2	1.5
Habitat loss	1.8	11	1.5	4.8	3	2.7	1.0	3	1.3	1.0	5	1.0	.	.	.
Population low/unoccupied habitat	2.7	11	2.3	2.0	6	2.2	2.9	2	2.5	3.8	3	2.3	.	.	.
Restricted access	2.8	12	2.6	2.3	7	3.0	4.6	1	2.0	2.5	4	2.0	.	.	.
Pollution	3.4	8	2.1	2.2	5	2.0	6.9	1	3.0	5.0	2	2.0	.	.	.
Lack population information	4.1	10	3.2	3.1	4	2.3	3.3	3	4.3	5.5	3	3.3	.	.	.
Multiple resource conflicts	4.1	5	1.6	4.0	2	1.5	2.3	1	1.0	5.0	2	2.0	.	.	.
Excessive demand	5.5	7	3.0	4.0	4	3.0	.	.	.	5.0	3	3.0	.	.	.
Interspecific competition	6.0	6	2.8	10.8	1	2.0	.	.	.	4.4	4	3.5	1.3	1	1.0
Lack info. on public/public support	6.9	6	3.2	8.1	2	3.0	11.5	1	5.0	4.5	3	2.7	.	.	.
Excessive harvest	9.6	2	1.5	5.4	1	1.0	4.6	1	2.0	.	.	.	.	.	.
Habitat management constrained/ineffective	12.9	2	2.0	.	.	.	6.9	1	3.0	5.0	1	1.0	.	.	.
Other population-related problems	19.3	2	3.0	8.1	2	3.0	.	.	.	.	.	.	.	.	.
Limited resource planning	25.7	1	2.0	.	.	.			.	10.0	1	2.0	.	.	.
Illegal harvest	25.7	1	2.0	10.8	1	2.0	.	.	.	.	.	.	.	.	.
Disease/parasites	28.9	2	4.5	21.5	1	4.0	.	.	.	25.0	1	5.0	.	.	.
Other habitat-related problems	38.6	1	3.0	.	.	.	6.9	1	3.0	.	.	.	.	.	.
Enforcement of regs./inadequate regs.	64.3	1	5.0	26.9	1	5.0	.	.	.	.	.	.	.	.	.

Note: f = frequency.

impoundments, siltation of spawning beds, point and nonpoint sources of pollution, water withdrawals, and increased temperature associated with low flows and low streamside cover all interact to eliminate or significantly reduce the quality of coldwater fish habitat.

As with other groups, habitat management issues have an associated concern for multiple resource conflicts. Agricultural land uses can increase sediment loads and pollution; timber harvesting and associated road-building can alter protective streamside vegetation and also increase the amount of sediments reaching coldwater streams; and cattle grazing in riparian zones can significantly alter vegetation and stream bank structure which are important cover components of fish habitat.

In addition to habitat issues, insufficient information on population status, population parameters, and harvest were also cited as an important deficiency constraining effective management. Potential productivity and harvest pressure can vary considerably from one water body to the next, and detailed inventory information is required to plan for a balanced and efficient use of coldwater fishery resources.

Restricted access was also identified as a management issue constraining efficient use of resident coldwater fishery resources. Access was a particularly important problem in the North where the proportion of public land is low. Access was less of a concern in the South, presumably because public land access is available in the few locations where coldwater habitats occur.

Of the 18 coldwater fisheries issues identified by the states, no identifiable regional profile emerged, suggesting that the issues are generally consistent throughout the nation.

Resident Warmwater Fish

Of the 17 management issues identified for warmwater fisheries, habitat degradation was the most frequently cited and had the highest management priority (table 57). Warmwater habitats are frequently associated with many of the most intensive human uses of the environment, and pollution and other forms of habitat degradation are a significant consequence. While significant progress has been made in improving the nation's warmwater rivers and streams in recent years, water quality was still the number one issue with state agencies. Excessive nutrients from point and nonpoint pollution sources stimulates high phytoplankton blooms causing dissolved oxygen levels to drop below threshold levels needed to sustain the fishery (Boyd 1979). As reviewed by Fajen (1981), other important factors contributing to habitat degradation involve stream channelization which eliminates alternating pool and riffle zones, floodplain development which destablizes the floodplain, and water withdrawals resulting in low instream flows. Loss of important wetland spawning and nursery habitats affects many fish, such as the pikes.

Management concerns related to excessive demand and restricted access are frequently correlated. Accessible warmwater fishing areas are often forced to sustain excessive levels of use that could be alleviated with increased area of fishable water open to the public. Both fish populations and recreational satisfaction are diminished under crowded conditions.

As was the case for coldwater fisheries, inadequate information on populations and harvests of warmwater species is also a major concern. Resource decision-making

Table 57.—Management issues for resident warmwater fish identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

	National			North			South			Rocky Mountain			Pacific Coast		
Management issue	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat degradation	1.0	23	2.0	1.0	7	2.0	1.0	6	2.0	1.0	10	2.0	.	.	.
Habitat loss	1.8	13	2.0	1.8	5	2.6	1.7	3	1.7	1.6	5	1.6	.	.	.
Excessive demand	2.1	12	2.2	1.1	6	1.8	6.0	1	2.0	2.6	5	2.6	.	.	.
Lack population information	2.2	12	2.3	1.0	7	2.0	3.8	2	2.5	5.0	3	3.0	.	.	.
Pollution	2.3	9	1.8	1.3	5	1.8	1.5	2	1.0	6.3	2	2.5	.	.	.
Restricted access	3.1	10	2.7	2.0	4	2.3	6.0	2	4.0	4.5	3	2.7	2	1	2
Population low/unoccupied habitat	4.4	7	2.7	5.3	2	3.0	.	.	.	2.6	5	2.6	.	.	.
Multiple resource conflicts	5.8	2	1.0	3.5	1	1.0	3.0	1	1.0	.	.	.	.	.	.
Lack info. on public/public support	6.4	5	2.8	2.7	3	2.3	.	.	.	8.8	2	3.5	.	.	.
Interspecific competition	7.7	3	2.0	.	.	.	9.0	1	3.0	10.0	1	2.0	1	1	1
Enforcement of regs./inadequate regs.	8.1	4	2.8	7.0	2	4.0	3.0	1	1.0	10.0	1	2.0	.	.	.
Declining/low demand	9.5	4	3.3	10.5	1	3.0	.	.	.	5.5	3	3.3	.	.	.
Excessive harvest	11.5	1	1.0	.	.	.	3.0	1	1.0	.	.	.	.	.	.
Lack habitat info. (requirements/inventory)	14.4	2	2.5	3.5	1	1.0	.	.	.	20.0	1	4.0	.	.	.
Habitat management constrained/ineffective	14.4	2	2.5	.	.	.	3.8	2	2.5	.	.	.	.	.	.
Limited resource planning	17.3	2	3.0	.	.	.	3.0	1	1.0	25.0	1	5.0	.	.	.
Population distribution inadequate	23.0	2	4.0	.	.	.	.	.	.	10.0	2	4.0	.	.	.

Note: f = frequency.

Table 58.—Management issues for nongame species identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

	National			North			South			Rocky Mountain			Pacific Coast		
Management issue	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Lack population information	1.0	25	1.8	1.0	10	1.8	1.1	5	1.6	1.0	9	2.0	2.7	1	2.0
Lack info. on public/public support	1.1	27	2.1	1.3	8	1.8	1.0	7	2.1	1.0	11	2.4	4.0	1	3.0
Habitat loss	1.3	21	2.0	1.6	6	1.7	1.0	7	2.1	1.5	6	2.0	1.3	2	2.0
Lack habitat info. (requirements/inventory)	2.8	10	2.0	6.9	2	2.5	4.2	2	2.5	1.7	5	1.8	1.3	1	1.0
Limited resource planning	2.9	12	2.5	3.2	4	2.3	1.7	4	2.0	3.8	4	3.3	.	.	.
Habitat degradation	3.0	12	2.6	3.3	5	3.0	5.0	2	3.0	3.5	3	2.3	1.0	2	1.5
Population low/unoccupied habitat	6.9	2	1.0	.	.	.	.	.	.	4.6	1	1.0	1.3	1	1.0
Multiple resource conflicts	6.9	4	2.0	2.8	2	1.0	6.7	1	2.0	18.3	1	4.0	.	.	.
Enforcement of regs./inadequate regs.	6.9	6	3.0	4.2	4	3.0	13.3	1	4.0	9.2	1	2.0	.	.	.
Interspecific competition	13.9	1	1.0	.	.	.	.	.	.	.	.	.	1.3	1	1.0
Habitat diversity loss	13.9	1	1.0	.	.	.	3.3	1	1.0	.	.	.	.	.	.
Pollution	17.1	3	3.7	11.1	2	4.0	.	.	.	.	.	.	4.0	1	3.0
Habitat management constrained/ineffective	18.5	3	4.0	.	.	.	10.0	1	3.0	10.3	2	4.5	.	.	.
Increased human populations	20.8	2	3.0	.	.	.	3.3	1	1.0	22.9	1	5.0	.	.	.
Excessive demand	55.6	1	4.0	22.2	1	4.0	.	.	.	.	.	.	.	.	.
Hunter ethics	55.6	1	4.0	22.2	1	4.0	.	.	.	.	.	.	.	.	.
Restricted access	69.4	1	5.0	27.8	1	5.0	.	.	.	.	.	.	.	.	.

Note: f = frequency.

requires population and harvest data to recommend management actions and to evaluate the success of such activities. Currently, this capability appears to be generally lacking with warmwater fish and many other species groups.

Nongame Wildlife

Unfortunately, nongame species individually and collectively enjoy less data accumulation than game species. Therefore, the most important management concerns were the lack of information about nongame population status, habitat requirements, habitat inventories, and public attitudes and use (table 58). Basic information on population trends and habitat needs is required for effective incorporation of nongame wildlife into multiple resource planning. The states cite both as being inadequate at this time. A similar finding, reported by the USDI Fish and Wildlife Service (1982a), revealed that in 31% of the considered cases, reasons for declines among bird species identified as having declining or unstable populations were either unknown or the species were not adequately monitored. The paucity of information regarding nongame wildlife is widely recognized and a number of workshops have been held to improve the information base on regional aspects of nongame communities and their management (DeGraaf 1978, 1979, 1980; Smith 1975). However, the focus of these workshops has been heavily biased toward nongame birds. Information on nongame mammals, reptiles,

amphibians, fish, and invertebrates has been more difficult to obtain. Even for the relatively well studied class of birds, efficient and accurate estimates of populations cannot be accomplished with current methods (Verner 1985).

Existing information about nongame species, however, does suggest that habitat loss is as much of a concern for this group as for others. Forest management practices influence forest succession, which in turn affects the fauna inhabiting a site at any given time. As forests are managed more intensively, the tendency is to shorten the successional process which can effectively eliminate the habitat for species requiring mature forest stands. Intensive, even-aged forest management can simplify stand structure, can reduce or eliminate special habitat components such as snags for cavity-nesting species, and can also affect the landscape diversity of forest types and successional stages.

Similar concerns for nongame wildlife inhabiting rangeland types exist and are associated with agricultural development and livestock management. Cultivation eliminates grassland communities, grazing can alter vegetation composition and impact special habitat components such as riparian areas in arid climates, and the seeding of exotic species can impair native floras. All negatively impact wildlife communities.

Urbanization associated with expanding human populations is a common disturbance factor on both forest and rangeland environments. Urbanization results in the removal or alteration of natural vegetation which can significantly affect the native fauna. The effect of urbanization on nongame bird communities has shown that, overall, species diversity declines with the avifauna becoming dominated by a few common, often exotic, species (DeGraaf 1986, Geis 1974).

The preceding discussion is not meant to imply that forest and rangeland management for timber or livestock is consistently detrimental to nongame communities. Rather, nongame wildlife represents such a diverse array of species that forest or rangeland management that fails to recognize the animals' habitat needs will tend to reduce the natural biotic diversity characteristic to a particular region. Given that information on nongame communities is lacking, no one can ensure that the habitats of all species will be maintained.

Threatened and Endangered Species

Management issues identified by state biologists were pertinent to species on both federal and state endangered species lists. The major concerns of the states for threatened and endangered species were the loss and degradation of habitat (table 59). These issues were consistent with the information provided by the USDI Fish and Wildlife Service's Endangered Species Information System as reviewed in chapter 1. The frequency with which habitat loss was cited, however, is inflated since state lists often include species occurring at the periphery of their ranges. Consequently, habitat may have been historically rare within a particular state as opposed to being recently lost through resource or human development.

Since part of the basis for a species to be considered threatened and endangered is a low population level, finding that states listed this as an important management issue is not surprising. However, population levels of these species have declined to the point where the genetic consequences must now be considered. As populations reach critically low levels, genetic variability is lost which can ultimately reduce the probability of species survival and recovery (Schonewald-Cox et al. 1983).

The other major management concerns for threatened and endangered species were the lack of adequate information about species population levels, habitat requirements, and public attitudes, which in turn limit effective incorporation of threatened and endangered species into comprehensive resource planning efforts. These

Table 59.—Management issues for threatened and endangered species identified by state wildlife and fish management agencies in order of national priority (rank of 1.0 represents issue of greatest concern).

	National			North			South			Rocky Mountain			Pacific Coast		
Management issue	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank	Index of importance	f	Mean rank
Habitat loss	1.0	22	1.9	1.9	6	1.8	1.0	7	1.9	1.0	7	1.9	1.7	2	2.5
Lack population information	1.0	19	1.6	1.1	8	1.4	2.5	3	2.0	1.1	6	1.8	1.0	2	1.5
Lack habitat info. (requirements/inventory)	1.3	17	1.8	1.0	7	1.1	5.5	2	3.0	1.1	7	2.0	2.7	1	2.0
Habitat degradation	2.0	14	2.3	5.7	3	2.7	3.7	3	3.0	1.0	6	1.7	1.7	2	2.5
Lack info. on public/public support	2.5	11	2.3	4.2	3	2.0	2.1	4	2.3	2.8	3	2.3	4.0	1	3.0
Population low/unoccupied habitat	3.6	6	1.8	6.4	1	1.0	7.4	1	2.0	2.8	3	2.3	1.3	1	1.0
Limited resource planning	3.6	7	2.1	4.0	4	2.5	3.7	2	2.0	.	.	.	1.3	1	1.0
Multiple resource conflicts	7.9	3	2.0	3.2	2	1.0	.	.	.	14.7	1	4.0	.	.	.
Enforcement of regs./inadequate regs.	8.9	4	3.0	11.1	2	3.5	11.1	1	3.0	7.4	1	2.0	.	.	.
Disease/parasites	8.9	2	1.5	.	.	.	.	.	.	7.4	1	2.0	1.3	1	1.0
Increased human populations	10.7	3	2.7	9.5	2	3.0	7.4	1	2.0	.	.	.	.	.	.
Habitat management constrained/ineffective	14.8	2	2.5	.	.	.	4.6	2	2.5	.	.	.	.	.	.
Pollution	17.8	2	3.0	9.5	2	3.0	.	.	.	.	.	.	.	.	.
Interspecific competition	20.8	2	3.5	.	.	.	.	.	.	18.4	1	5.0	2.7	1	2.0
Excessive demand	47.5	1	4.0	25.5	1	4.0	.	.	.	.	.	.	.	.	.
Hunter ethics	47.5	1	4.0	25.5	1	4.0	.	.	.	.	.	.	.	.	.
Illegal harvest	59.4	1	5.0	.	.	.	.	.	.	18.4	1	5.0	.	.	.

Note: f = frequency.

issues are related, in part, to the ownership pattern of remaining habitat. Several states claimed that threatened and endangered species management could not be effective on private lands, citing landowners' lack of concern for the species, limited regulatory authority, and inadequate public understanding about the basis for the states' concern for these species.

Issues Perceived on Public Lands

The Forest Service (FS) and Bureau of Land Management (BLM) are responsible for managing wildlife and fish resources on approximately 525 million acres. Although the states technically have the lead responsibility in the management of resident wildlife and fish populations, the FS and BLM are responsible for managing wildlife and fish habitats. However, strict adherence to this division of responsibility would foster inefficient management of wildlife and fish resources. Consequently, wildlife and fish management is, in practice, conducted through cooperation among state and federal agencies.

The FS and the BLM are multiple-use agencies which by definition means that decisions have to be made as to how lands are used among a variety of competing uses. In many cases, the source of the wildlife and fish management issues facing these two agencies can be traced to this multiple resource management responsibility. Biologists from both agencies were asked to provide a priority listing of the major management issues for each species category. Because of the high degree of cooperation between federal and state agencies, many of the issues are similar to those cited by state personnel.

Forest Service

Biologists provided information on the most important management issues facing wildlife and fish resources in their region. As with the state agencies, the issues varied across the species groups.

For big game species, a major habitat management issue concerned the effect of intermingled land ownerships. Big game species range widely and independently of ownership boundaries. Effective management of big game species on national forests was often viewed as being constrained by human development and resource management on surrounding private lands. This was especially a concern in the West where development of private lands is resulting in losses of important winter ranges, and in the East where private ownerships dominate. Other important habitat-related problems included: (1) a noted decline in shade-intolerant timber types (e.g., aspen, jack pine) through natural forest succession which has reduced the amount and quality of deer and moose habitat in the North; (2) reduction in winter thermal cover (lowland conifer and cedar) in the North; and (3) maintenance of a suitable mosaic of old-growth and second-growth stands for species such as Sitka black-tailed deer in Alaska.

Management issues related to the recreational use of big game were also a prominent concern and were largely related to the distribution of that use. In some cases, hunting pressure and excessive access have increased on national forests as hunting opportunities declined on private ownerships. Road development associated with timber harvesting has increased the accessibility of game to the public and in some instances has facilitated the illegal harvest of deer and black bear. Conversely, in some cases restricted access was the concern. For example, private landowners can deny passage through their property to national forest land, and major portions of some national forests remain undeveloped and inaccessible to big game hunters. The composite result of both access issues is an inadequate distribution of big game recreational use.

A final concern for big game management is that multiple uses of national forests often conflict with big game management objectives. This issue translates into a general concern for adequate integration of wildlife into the resource planning process.

Traditionally, small game and waterfowl have received less emphasis in the resource planning process on national forests. The habitat-related concerns that were raised centered around three issues: (1) loss of both early and late forest seral stages, (2) livestock grazing impacts on riparian and other wetland habitats, and (3) declining quantity and quality of wetland habitats on public and private lands. Other management problems associated with small game and waterfowl derived from the low priority that these species have received in the past. These included a general lack of population and habitat inventory information. In some regions, biologists felt that the resource was underutilized by the public.

Approximately 50% of salmon and steelhead spawning and rearing habitat occurs on national forests in Oregon, Washington, and Idaho; in Alaska the estimate is 27% (Barton and Fosburgh 1986). However, biologists have noticed fewer spawners returning to the headwaters on national forests resulting in an underutilization of available habitat. FS biologists also noted habitat degradation problems associated with livestock grazing, sedimentation from timber harvesting and road development, lack of overhead cover resulting in high water temperatures, and low pH in some eastern streams. Other management issues that constrain effective planning for anadromous fish included inadequate information on habitat condition, the cumulative impacts of forest management, and the economic benefits and levels of recreational use of the fishery.

Resident cold- and warmwater fishery resources share many habitat concerns with the anadromous fishery. In the West, habitat management issues focused on the loss of streambank structure and vegetation due to livestock grazing and poor implementation of recommended streamside silvicultural practices. In the East, habitat concerns involved low streamside cover which elevates water temperature, low pH, and nuisance aquatic vegetation which promotes stunting among panfish populations and hinders fishing. Stunted panfish was also the result of inadequate predators. As with anadromous fish, an important management issue was the lack of adequate

information on habitat, populations, factors limiting productivity, and the effectiveness of direct habitat improvements.

The National Forest Management Act of 1976 (NFMA) mandated the FS to maintain a diversity of plant and animal communities and to ensure viability of all animal species inhabiting the NFS. Consequently, wildlife and fish management and planning must consider the animal community in its entirety, including nongame species which constitute the majority of species found on national forests. A frequently cited nongame management issue raised by FS biologists related directly to the viability requirement. Insufficient information on nongame population status and habitat requirements confound their responsibility to demonstrate that viability of species will be assured. A contributing factor to the inventory problem is the implied number of wildlife and fish species that must be monitored. The NFMA recognizes this concern and requires the designation of species which "indicate" the trends of other species with similar habitat requirements. However, the basic assumption underlying this approach (i.e., that the status of one species is representative of the status of several species) has been challenged (Block et al. 1987, Landres 1983, Mannan et al. 1984, Szaro 1986, Verner 1984). As a result, considerable uncertainty exists in the selection and use of indicator species in resource planning for nongame species.

In addition to concerns stemming from the requirement for maintaining viable populations, important nongame management issues involved quantity and quality of habitat. In particular, the disappearance of old-growth forests, poor distribution of age classes, and loss of bottomland hardwoods were of concern in the East. Key issues raised in the West were provision of adequate habitat for cavity-nesting species, maintenance of old-growth forest habitats for such species as the spotted owl, loss of aspen communities to succession, and the degradation of riparian habitats from livestock grazing practices.

A particularly important subset of nongame wildlife and fish are those species that are currently listed as threatened and endangered. The FS consults with the Fish and Wildlife Service to ensure recovery of listed species. Species of particular concern include the grizzly bear, California condor, red-cockaded woodpecker, Kirtland's warbler, woodland caribou, bald eagle, peregrine falcon, Puerto Rican parrot, Lahontan cutthroat and greenback cutthroat trout, and the gray, Indiana, and Virginia big-eared bats. By definition, concern for low populations and maintenance of habitat are of primary concern for these species. However, other management issues included the lack of comprehensive information on the distribution of all threatened and endangered species on national forests, intermingled ownerships hindering effective management and limiting the recovery of some species, and conflicts between public use in areas with high access and species requiring limited human disturbance.

Bureau of Land Management

BLM biologists from western states provided information on wildlife and fish management issues of primary importance to the agency. In general, the management issues identified are consistent with those issues identified by FS and state biologists. The discussion here will focus on those issues emphasized as particularly important on BLM lands.

Without question, the most important wildlife and fish management issue cited by BLM biologists was the effect of livestock grazing. BLM lands have a history of overgrazing, and although range conditions have improved somewhat, the majority of the public range is still seriously deteriorated and producing far below its potential (Barton 1987). Degraded rangeland condition particularly affects big game winter ranges, which are prevalent on BLM lands, and small game habitats.

Another important issue related to grazing was the impact of livestock on riparian communities. Riparian areas are critical to wildlife and fish, particularly in arid climates. In the West, riparian systems support a disproportionate number of wildlife species when compared to adjacent upland ecosystems (Ohmart and Anderson 1986). Livestock also make disproportionate use of riparian systems, and BLM biologists cited maintenance and recovery of riparian ecosystems more frequently than any other management issue across all species groups.

Other habitat-related issues included adequate distribution of water, conflicts with mineral development, unoccupied desert bighorn sheep habitat, noxious weed infestation, and encroachment of undesirable woody species.

Intermingled ownerships were also cited as a hindrance to effective wildlife and fish management. Instances exist where key habitat features exist on private ownerships and therefore are beyond the management jurisdiction of the BLM; access to BLM lands is often restricted under such ownership patterns; and intermingled ownerships also result in ineffective resource planning unless there is a high degree of cooperation among all land owning parties.

Throughout much of its existence, the BLM lacked the authority and funding to manage its lands (Barton 1986). The agency's mandate to manage for multiple uses is relatively recent. As a consequence of this history, BLM biologists have cited limited inventory information on the amounts and quality of wildlife and fish habitats, the status of wildlife and fish populations, ecological relationships between animals and their habitat, and the distribution of threatened and endangered species as restrictions on effectual multiple use planning.

WILDLIFE AND FISH MANAGEMENT OPPORTUNITIES

Wildlife and fish management has been defined as the art and science of "changing the characteristics and interactions of habitat, wild animal populations, and men in order to achieve specific human goals" (Giles 1969:1). As defined by Poole and Trefethen (1978),

the primary goal of wildlife and fish management is to maintain animal populations at levels that are consistent with the capacity of the ecological system and the social, economic, and cultural needs of the public. Failure to manage wildlife and fish resources would almost certainly lead to the domination of generalist species rather than a balanced interacting fauna (Bolen and Rodiek 1986, Lyle 1985). Berryman (1983:473) asked the questions: "Do we want only to preserve islands of habitat, only remnants of fish and wildlife populations? Or do we want fish and wildlife resources to remain as a part of the fabric of our total landscape and environment?" The management opportunities discussed here are in the spirit of the latter; however, the former is a possible future for some species and communities.

The management issues identified by state and federal agencies were classified into four categories: habitat, population, user, and planning-related issues. This categorization is also appropriate for discussing future wildlife and fish management opportunities. The order in which these aspects of wildlife and fish management are listed is not arbitrary. Habitat is often the factor most limiting to wildlife and fish species, and it makes little sense to consider population manipulations if the habitat does not exist. By the same logic, regulation of users becomes unnecessary when wild populations are not present to be enjoyed by the recreating public. Planning is listed last as it involves all aspects of wildlife and fish management, and in a world of competing uses, must also consider aspects of management across multiple resource areas.

Habitat Management Opportunities

Management issues related to wildlife and fish habitat focused on two aspects. The first was a concern for the loss or total removal of certain habitat types from the landscape. The second was a concern for degradation or the reduced quality of habitats and was usually associated with multiple resource conflicts.

The most obvious management opportunity involves the outright purchase of land. This gives the resource managing agencies control over land-use activities that would otherwise jeopardize the existence of the habitat. Probably the best example where acquisition has been critical to the preservation of a habitat type is the protection of wetland habitats under the National Wildlife Refuge System. Under such programs as the Migratory Bird Hunting and Conservation Stamp, the Wetlands Loan Act, and the Land and Water Conservation Fund, the Refuge System has grown to 90 million acres (Office of Technology Assessment 1984). The Endangered Species Act also authorizes the purchase of land for the protection of critical habitat.

Another important land acquisition opportunity exists through established natural area programs. State (Schwegman 1983), private (Cantera 1983) and federal (Burns 1983) natural area programs have all contributed to an extensive network of protected plant and animal communities. As of 1983, the Fish and Wildlife Service had designated 194 natural areas followed by the FS (148), National Park Service (64), and the BLM (23) (Burns 1983). The BLM also has special authority to designate and protect Areas of Critical Environmental Concern (ACEC). Protection of rare floras and faunas is a prominent objective of this program. The BLM now has approximately 300 ACEC's that cover over 5 million acres (Almand, pers. comm., 1988).

Coordination and cooperation among private, state, and federal programs will be critical to the effective management of these lands in the future (Harwell 1983). Consideration must be given to the size, shape, distribution, and linkages among communities of the same type if the goal of preserving natural diversity is to be attainable. As noted by Hoose (1983), the effect that large-scale disturbance factors such as acid rain, global warming, depletion of aquifers, and air and water pollution will have on the viability of some natural area communities remains unknown. Similarly, protected communities may lose integrity at their borders as private land uses intensify. The implication is that the management of natural areas will have to become more intensive and involve considerations on a broader landscape scale. For example, corridors of habitat to connect nature reserves have been proposed as being important in facilitating gene flow to maintain the ecological integrity of rare and isolated communities (Harris 1984, Office of Technology Assessment 1987).

Protection through purchase is in most cases limited by inadequate funds. The partial purchase of property rights through conservation easements, long-term leasing agreements, or management agreements with landowners have been used effectively in wildlife and fish habitat protection as alternatives to purchase (Gilbert and Dodds 1987). Private landowner incentive programs offer still another habitat protection opportunity that can range from wildlife habitat management assistance to preferential tax treatment for landowners who preserve wildlife habitat. The Sodbuster, Swampbuster, and conservation easement provisions of the 1985 Food Security Act (see chapter 3) provide examples of where such wildlife habitat protection opportunities have recently been implemented.

Protection, through purchase or otherwise, of wildlife and fish habitats is rarely sufficient to maintain the quality of the habitat into the future. The majority of the nation's wildlife and fish habitats exist under a resource management environment of competing uses for the land. Consequently, the general situation facing wildlife and fish managers is that the creation and enhancement of wildlife and fish habitats must be coordinated with other land and resource uses.

Reduced to its most fundamental principles, all forms of habitat restoration or enhancement involve the manipulation of wildlife and fish food, cover, and water in both time and space. The specific habitat management activities that are implemented depend on management objectives; however, some examples of habitat management opportunities are discussed below.

Restoration of degraded ecosystems has a relatively short history in the United States and probably saw its

beginnings with the restoration efforts of prairie ecosystems initiated by Aldo Leopold (Jordan et al. 1987). Out of those initial efforts grew an understanding of fire's role in prairie ecosystems. Since that time, research has demonstrated the important role that fire plays in the maintenance of many range and forest communities. Since the 1970's, many national parks and wilderness areas have been managed under a "let it burn" policy, but this may change as we learn about the consequences of such a policy. Passive management of fire, however, is not always feasible and deliberate controlled burns are a valuable wildlife management tool for improving habitat for wild ungulates (Scotter 1980) and other game and nongame species associated with or dependent on early successional stages (Landers 1987, Peek 1986).

Wildlife and fish restoration may also take the form of simply removing or more effectively controlling disturbance factors. In some cases, resting riparian areas from livestock grazing has been shown to be effective in restoring streamside vegetation communities (Kauffman and Krueger 1984) with associated benefits to both terrestrial and aquatic animals. Wetlands can sometimes be restored by eliminating cultivation and rendering drainage systems ineffective (Office of Technology Assessment 1984). Control of point and nonpoint sources of pollution will allow aquatic ecosystems to recover. Reductions in the use of certain pesticides has helped in the recovery of some raptor populations (Evans 1982). Removal of barriers to migrating anadromous fish represents an opportunity to significantly increase the production on spawning habitats. The Northwest Power Planning Council (1987) is examining a number of structural modifications to fishways that will increase the number of returning adult spawners and reduce mortality to juveniles during downstream migration.

More intensive restoration efforts could involve the direct manipulation of food and cover through seeding, planting, or chemical applications to control noxious or undesirable plants. Aquatic habitat developments also represent an intensive form of restoration management that includes the creation of wetland habitats, water facilities for wildlife in arid climates, structures to enhance the within-stream cover, and small ponds for warmwater fish habitat.

Habitat restoration through direct manipulation of food, cover, and water for the sole purpose of enhancing wildlife and fish habitat is often prohibitively expensive. More efficient habitat management can be attained through the integration of habitat management considerations into the management of other resources. Fundamentally, incorporating wildlife and fish habitat concerns into multiple resource management systems entails ensuring that habitat diversity is maintained. Three aspects of habitat diversity are important. The first aspect is vertical diversity, or the number of vegetation layers present within a given plant community. However, wildlife and fish are mobile resources and therefore require consideration of a horizontal diversity component to habitat as well. The size, shape, and distribution of vegetation types and successional stages in a given area and through time are important to the maintenance of the regional animal community. The final aspect of wildlife and fish habitat diversity is the presence of special habitat components including snags, caves, talus slopes, cliffs, and dead and down woody material. The absence of such special components will result in some species being absent from the community.

Timber and livestock management practices can all be modified to ensure that these aspects of habitat diversity are provided. Wildlife and fish can benefit from timber and livestock management, but only if planned for in advance. Timber harvesting methods, harvest rotations, and intermediate silvicultural treatments can be used to enhance or maintain, rather than limit the quantity and quality of wildlife and fish habitat (Everest et al. 1987, Harris 1984, Thomas 1979). Similarly, grazing systems, season of use, multiple species grazing, and livestock improvement practices (e.g., water facilities, control of noxious plants, fire) can be used to minimize impacts to riparian systems or even enhance habitat quality for wild ungulates on winter ranges (Joyce in press, Scotter 1980). Although integration of wildlife and fish management into timber and range management may carry costs (no single resource output is maximized), it will ensure that certain values, some of which are difficult to quantify, will not be excluded.

Integrated wildlife and fish management certainly represents a viable management opportunity under public lands with multiple use objectives. However, it should not be assumed that integrated resource management is not feasible on private lands. Opportunities exist for state and federal agencies to provide technical assistance to private landowners who desire to manage wildlife and fish habitats on their lands. Opportunities to assist private landowners could be expanded in the future. Under the 1985 Food Security Act, substantial acreage of highly erodible cropland will be planted to permanent cover which, if appropriate species are chosen, can provide high quality habitat for wildlife and improve fish habitat by reducing soil erosion into aquatic ecosystems. In addition, private landowners, including large industrial timber companies, are now entering into lease agreements with hunters and anglers or charging access fees for the privilege of using their lands. McKee (1987) showed that net revenues from the joint production of wildlife and timber under fee hunting situations in the South were greater than revenues generated from maximizing timber production. Such economic incentives may provide the motivation for active wildlife and fish management on private lands, and state and federal agencies have the opportunity to assist in guiding that management.

Population Management Opportunities

Although habitat management may provide the greatest opportunities for improving future wildlife and fish resources, in some cases actual manipulation of populations is required to address certain management issues. Wildlife managers can often manipulate animal numbers

through properly planned harvests more effectively than manipulating environmental factors to improve habitat (Scotter 1980). Under these situations, the goal is one of preventing habitat deterioration stemming from overly abundant wildlife. One of the more important management problems noted by the states was excessive populations of some big game species. Number of licenses, hunting season lengths, and either-sex regulations can all be adjusted to balance big game populations with the environment's capacity. The states have the primary authority for the setting of harvest regulations for resident game populations and population management through exploitation will continue to be an important responsibility of state agencies.

Another management issue raised by state and federal agencies was the prevalence of unoccupied habitat. Transplanting of wild stock offers an opportunity to hasten colonization of suitable habitat—assuming that the disturbance factor responsible for the species displacement has been removed (e.g., competing species). This technique was used effectively in reestablishing white-tailed deer (Downing 1987) and wild turkey (Lewis 1987) populations in the East. Transplanting animals into suitable habitat represents one of the most important opportunities for maintaining threatened and endangered species. Captive breeding programs and subsequent reintroduction into suitable habitat are critical to the restoration of such species as the peregrine falcon, red wolf, California condor, Puerto Rican parrot, greenback cutthroat trout, and black-footed ferret.

Aquaculture, the propagation of aquatic species in controlled environments, represents a general management opportunity that has both recreational and commercial application (Parker and Stevens 1988). Fish hatcheries, although important in the restoration of some endangered fishes, have their greatest utility in supplementing heavily exploited fish populations. A significant portion of the commercial and recreational harvest of sport fish is produced in hatcheries. However, artificial propagation should not be considered a substitute for natural reproduction (Everhart and Youngs 1981).

Given expected demand increases for commercial fish products and recreational fishing, aquaculture will likely become a more prominent management practice used to meet these rising demands on the nation's fishery resources. It has been estimated that aquaculture in the United States will produce 2 billion pounds of fish by the year 2000 (Parker and Stevens 1988). Stock-enhancement through aquaculture will also continue to be important in maintaining recreational fishing opportunities, particularly in and around high population centers.

Increased production from aquaculture can be accomplished through improved propagation practices which increase survival, increasing the capacity of existing facilities, and the building of new rearing facilities. For example, the Northwest Power Planning Council (1987) has found that acclimation ponds can improve survival of released fish and is recommending the development of low-cost, small-scale hatcheries. Smaller scale hatcheries have the advantage of smaller water supply requirements and they are readily adaptable to an individual drainage which facilitates the preservation of gene pools.

Other management opportunities that involve the direct manipulation of populations include the removal of pest or competing species. For example, certain bird species have a long history of damaging crops and causing health problems. When populations become excessive, intensive measures to control their numbers may have to be implemented. However, Dolbeer and Stehn (1979) pointed out that such measures may only be temporary solutions and recommended that studies be initiated to determine the cause for population increases so that longer term solutions can be achieved. In the case of interspecific competition, removal of the competing species may be the only possible solution to the management problem and has been an important management practice in the protection of threatened and endangered species such as the Kirtland's warbler (Walkinshaw and Faust 1974) and Hawaiian birds (Scott and Sincock 1985).

User and People Management Opportunities

Management issues related to use of wildlife and fish resources focused mainly on concerns for access. The states control use through restrictions on the number of licenses available or through special regulations that attempt to control the distribution of user pressure within the state. However, if access to land or water supporting wildlife and fish is limited, regulations to control use can be ineffective and recreationists can become dissatisfied. From the state's perspective, restricted access was the fifth most important management issue across all species groups. The reasons for closing lands are varied and include concern for liability, property damage, interference with other activities, and disturbance of privacy. Another major factor is that the landowners have traditionally received little or no economic return for allowing hunting or fishing on their lands. Evidence reviewed in chapters 2 and 5 showed that economic return to private landowners stemming from wildlife and fish recreation has been increasing and will probably continue to increase in the future. Consequently, opportunities exist for state and federal programs to promote and assist landowners in establishing such businesses. A more active policy for lease hunting and fishing could put wildlife and fish agencies in a stronger position to take an active role in shaping lease agreements and ultimately provide an opportunity to work more closely with private landowners in the management of habitats (Wiggers and Rootes 1987).

On public lands, both restricted and excessive access were important management concerns. Opportunities to increase access to public lands involve adjustments to ownership patterns through land exchanges, acquisition, or easements. Solution of the restricted access problem must, in part, address concerns for excessive access by helping to redistribute use. Road closures in high use

areas provide one opportunity for controlling the potential detrimental impacts on the land, and wildlife and fish populations.

Another important management concern was an uninformed public. As competition among land uses intensifies, wildlife and fish managers will require that the public have a complete understanding of the management problems and the justification for proposed management activities. Without public acceptance, wildlife and fish management will be ineffective. Public information and education programs are an obvious opportunity for gaining public confidence and support for wildlife and fish management on private, state, or federal lands.

The concern for user information, however, does not stop with educating the public. Managing agencies must educate themselves on public attitudes and values. Such information can be useful in establishing the priority that should be assigned to various management activities. The clientele has changed and will continue to change in the future. The future demands for wildlife and fish recreation, based on the results presented in chapter 2, are expected to shift from hunting to fishing and nonconsumptive activities. Managing agencies will need to respond to these shifts or risk failure in fulfilling the stewardship obligations entrusted to the resource managing agencies.

Planning Opportunities

Planning involves the specification of objectives, implementation of management strategies, and an evaluation of how well objectives were met. Four factors cited as contributing to ineffective decision-making were: (1) inadequate cooperation among agencies, (2) poorly coordinated planning among resource areas, (3) inadequate information on population and habitat status, and (4) limited capability to predict animal response to resource management activities.

Cooperative and Coordinated Planning

Cooperative planning is particularly important for mobile resources such as wildlife and fish. Political and administrative boundaries have been defined without respect to ecological systems. Wildlife and fish planning and management under multiple and intermingled land ownerships can be futile for wide-ranging species or species inhabiting aquatic systems unless habitat conditions across all ownerships are considered. Cooperative planning across land managing agencies, landowners, and user groups has been recognized in the National Recreational Fisheries Policy (USDI Fish and Wildlife Service 1988c) as being critical to effective and efficient management of the nation's fishery resources.

Opportunities to improve the planning environment include consolidation of land ownerships through purchase or land exchange. In the FS, purchase and exchange of lands are authorized under the 1911 Weeks Act, the 1922 General Exchange Act, the Federal Land Policy and Management Act, and a number of laws authorizing the purchase or exchange of lands for specific purposes including the Wilderness Act of 1964, the Eastern Wilderness Act of 1975, the Endangered Species Act of 1973, the Wild and Scenic Rivers Act of 1968, and the Sikes Act of 1967. While the authority exists, proposals for large land exchanges between agencies have met with resistance. The 1985 proposal to exchange 35 million acres between the FS and BLM was delayed because interest groups felt that such land swaps should be evaluated on a case-by-case basis (Barton and Fosburgh 1986). While focus on smaller land units and the "politics" involved may engender a perception that land purchase and exchanges are ineffectual, it appears to be an unavoidable consequence of the process.

Coordinated planning among resource areas, as reviewed under habitat management opportunities, probably represents the single greatest opportunity for improving the future wildlife and fish resource situation. Leopold (1933) noted that wildlife and fish management is essentially the "favorable alignment" of timber, agriculture, and livestock activities. Despite the history behind the concept, and the acceptance of its importance in wildlife and fish management, it has been difficult to integrate wildlife and fish management into comprehensive land use plans (Peek 1986). Part of the difficulty stems from incomplete information on how wildlife and fish respond to various timber, livestock, and water management activities. Knowledge gaps defined by the state and federal agencies help define the future research needs related to effective planning and management.

Research Needs

The information needs identified by the state and federal agencies fell into three broad categories: (1) species-habitat relationships, (2) population inventories, (3) public attitude about wildlife and fish values. Species-habitat relationship information is basic to any management plan. Additional research on species-habitat relationships is important for at least two reasons. First, basic knowledge of species life requisites is necessary before we can manage existing systems in a manner that maintains the biological diversity typical of a given community. Second, such knowledge is important to restoration efforts of those habitats that have become rare including old-growth forests (Nyberg et al. 1987), wetlands (Pearce 1985), tallgrass prairie (Platt 1983), and riparian systems (Platts 1986).

Apart from providing a knowledge base from which to recommend management and restore communities, species-habitat relationship information is also important in the development of resource planning models. Since the last national assessment of wildlife and fish (USDA Forest Service 1981), researchers have expended considerable effort to develop quantified characterizations of wildlife and fish habitat in the form of species-habitat relationship models (Fausch et al. 1988, Verner et al. 1986). One objective of these habitat models is to aid planners in assessing the impacts from multiple resource management on wildlife and fish resources. The

value of these models is as a tool to explore potential outcomes based on what biologists believe to be the habitat requirements of modeled species (Starfield and Bleloch 1986). Research has provided the resource planner with a diversity of habitat modeling approaches; however, model development has exceeded model validation and testing of basic assumptions. The research challenge now is not to develop new techniques for modeling wildlife and fish habitat but to rigorously explore the basic underlying assumptions and to test the performance of extant modeling approaches (Fausch et al. 1988, Sweeney and Wolters 1986).

Another area of future research concerns the application and testing of wildlife and fish habitat models at larger scales. Most habitat modeling efforts have focused on site-specific studies, but policy and management decisions are being made at regional scales. There is increasing recognition that informed resource planning decisions cannot be made exclusively at the site-level (Risser et al. 1984) and that more emphasis needs to be placed on analyses that explicitly address large geographic areas (Gall and Christian 1984, Sanderson et al. 1979). As reviewed in chapter 3, the use of wildlife and fish habitat models to evaluate the impacts from timber management and land-use change represented the first time that regional wildlife and fish models were linked to regional timber inventory and land use models (USDA Forest Service 1988). The conceptual framework for regional multiple resource analyses has been described (Joyce et al. 1986) and applied in the South (Flather et al. 1989, Flebbe et al. 1988). Further research on regional multiple resource modeling is needed in the areas of: rigorous evaluation of model performance, extending the methodology to other regions of the country, and incorporating wildlife and fish, forage, and water feedbacks that alter timber management and land use decisions.

Apart from being used to predict wildlife and fish response to land management activities, an additional use of habitat models is to support wildlife and fish population monitoring. Habitat characteristics are easily inventoried relative to wildlife and fish populations. The basic assumption of this application is that changes in habitat amounts and quality can be used to predict changes in animal population levels. Recent research has shown, however, that this assumption does not hold for some species (Rotenberry 1986, Van Horne 1983), and that other factors (interspecific interactions, weather, disease, mortality on wintering habitat, etc.) must be considered when explaining variation in population levels. Additional research is needed to characterize those kinds of species where the assumption of population levels tracking habitat condition is and is not valid.

The implication of the uncertainty associated with the habitat-population relationship is that inventories of habitat alone will not be sufficient to ensure that community diversity and viable populations will be maintained. Both state and federal agencies expressed concern that information on population status and important population parameters was inadequate to manage the resource effectively. This was more of a concern with nongame species than for game species. Inventory information was available for some game mammals and birds, and some nongame bird species, yet generally absent for small mammals, fish, amphibians, reptiles, and invertebrates. Although local inventories of such species may be available for a specific site, systematic and comprehensive approaches to monitoring wildlife and fish populations are lacking. Existing methods are, in general, too expensive and of questionable accuracy. Recent suggestions to use indicator species or guilds to monitor wildlife and fish communities have potential shortcomings (Verner 1986). Future research directed at developing wildlife and fish monitoring techniques applicable across a variety of scales (site, management unit, region) is not only important for providing baseline information on population status, but it is also important in evaluating the predictive accuracy of species-habitat relationship models.

The final area of needed research, as reflected by state and federal agencies, is in characterization of the public attitudes and values held for wildlife and fish resources. Because state and federal management agencies are public agencies, they need to know who the public is, what the public desires, what the public is willing to pay, and the factors responsible for changes in these components (Lyons 1987). The attitudes and wants of consumptive wildlife and fish recreationists have been studied to a much greater degree than either nonconsumptive users or nonusers. Such information is critical if management agencies are to respond and adjust their programs to satisfy the public demands. Failure to do so will only result in an eroding of public support and declining funding levels.

Characterizing the client is but one important component of research addressing the human dimension of wildlife and fish resource management. Another important component concerns estimating the economic value of wildlife and fish resources. Such information is not only important to setting wildlife and fish management priorities, but it is also critical if wildlife and fish are going to compete on a commensurate basis with other resources under multiple use management. Although a number of techniques have been developed to estimate nonmarket wildlife and fish resource values, additional research is needed to test model assumptions and validate methodologies. There is also a need to extend the user projection analysis used in chapter 2 to more accurately examine the relationship between wildlife and fish resource inventories and participation in wildlife and fish related recreation (Lyons 1987). Finally, the growing prevalence of fee-hunting in the United States offers an opportunity to further study the economic value of wildlife and fish resources and its role in private land-use management decisions.

OBSTACLES TO IMPROVING WILDLIFE AND FISH RESOURCES

Obstacles are those factors that prevent implementation of effective management opportunities. Unmet management goals and objectives can lead to a dissatisfied clientele or deterioration of the resource itself. The

most common obstacles identified by state and federal agencies were lack of knowledge, inadequate or unstable funding levels, and inadequate staffing and qualified personnel.

Insufficient knowledge has two aspects. The first is that research is required to add to the information base on wildlife and fish management. The research needs discussed above in the areas of habitat relationships, population monitoring, and public attitudes and values address this aspect of insufficient knowledge.

The other aspect concerns increased information exchange between researchers and managers. An efficient system is needed to transfer knowledge from those solving management problems to those who have the responsibility of implementing these solutions. (Seitz et al. 1987). As described by Naisbitt (1982), the United States is evolving into an information based, high technology society. The wildlife and fish profession needs to take advantage of information transfer technology to ensure that managers are applying state-of-the-art techniques and researchers are informed of the evolving problems facing managers.

Concern for sufficient funding was by far the most frequently cited obstacle. As reviewed in chapter 5, many state agencies have experienced substantial declines in real spending power. Similar declines have been noted in federal agency budgets. Between 1980 and 1985, in constant dollars, the FS budget declined by 16%; funding for wildlife and fish habitat management on national forests declined by 9%; wildlife and fish research funding declined by 9%; and funding for the State and Private Forestry Program which provides technical assistance to private landowners declined by 38% (Barton and Fosburgh 1986). Similarly, funding appropriations for wildlife habitat management on BLM lands declined by 22% from 1981 to 1986 (Barton 1987).

Adequate staffing is not unrelated to agency budgets. However, number of personnel is only part of the concern. As resource management problems become more complex, the qualifications for addressing the problems change. Education of existing personnel and the training of new professionals must evolve with these changes to ensure that resource professionals can be effective. Recommendations for improved curricula and continued training include: (1) explore new approaches to motivate the work force to continue formal education opportunities (Hamilton et al. 1987); (2) increase the opportunities for participation in continuing education programs (Cross 1987), with increased employer responsibility to do so (Nielsen 1987); and (3) revision of natural resource curricula to include not only a biological background, but also an increased emphasis on courses in law, communications, political processes, economics, long-range planning, information management and computer science, and human resource management (Knuth 1987, Streeter 1987).

SUMMARY

An important component of national resource assessments is to explore the management issues and attendant management opportunities that exist for minimizing the social, economic, and environmental costs associated with future imbalances in anticipated resource use and inventories. Management issues and opportunities were categorized into four areas: habitat, population, user, and planning.

Priority management issues were identified from responses provided by state and federal biologists. At the national level, and for all species groups covered in this assessment, habitat loss and habitat degradation were ranked as the two most important wildlife and fish management issues. Habitat is the most fundamental management issue now confronting resource managing agencies, for landscapes lacking in suitable wildlife and fish habitats will no longer support animal populations.

Management concerns related to wildlife and fish populations were ranked as the third and fourth most critical national issues. Inadequate population inventory information was cited as hindering effective management of wildlife and fish. A general concern for low populations of some species groups was viewed as an area for potential future improvement.

User-related issues were also a prominent concern of wildlife and fish resource management agencies. Restricted access to both public and private lands has resulted in an inadequate distribution of recreation use and managers felt they had insufficient information on public attitudes and values held for wildlife and fish. The latter was emphasized as particularly important since it ultimately affects public support for management activities.

The final issue of national concern was related to multiple resource planning. More intensive agricultural practices and timber management, competition with livestock, mineral development, water withdrawals for consumption or irrigation, and wildlife damage to crops all serve to illustrate that wildlife and fish management is much more complicated than direct habitat improvement, manipulating animal populations, or regulating use.

The specific management opportunities addressing habitat-related issues included:

- Protection of key habitats (including wetlands, native grasslands, old-growth forests, fish spawning areas, and critical habitat for threatened and endangered species) through public purchase, easement, leasing agreement, or establishment of natural areas.
- Increasing the size, diversity, and distribution of key habitat tracts to preserve the natural diversity characteristic of a given region.
- Restoration of degraded ecosystems through: 1) direct manipulation of vegetation and water through seedings, plantings, physical or chemical treatment, creation of wetlands, and development of water facilities and stream structures, or 2) removal or effective control of disturbance factors including control of point and nonpoint sources of pollution, removal of barriers to migrating fish, controlling livestock access to riparian areas, and removal of wetland drainage systems.

Opportunities for direct management of wildlife and fish populations included:

- Manipulation of populations through appropriate harvest strategies to ensure that populations remain within the productive capacities of their habitat.
- Increasing the reintroduction of species into areas where they have been displaced from suitable habitat or where suitable habitat has been developed.
- Increasing fish hatchery production through improved propagation practices, increasing the capacity of extant facilities, and the building of new facilities.
- Control or removal of pest or competing species.

Opportunities for user and people management included:

- Improving access to private lands by promoting programs that would assist landowners in establishing wildlife and fish-related businesses.
- Increasing the use of land acquisition and user management programs to increase the amount of habitat available to recreationists and to better distribute use across suitable sites.
- Implementing programs to educate the public about the need for and objectives of wildlife and fish management.
- Implementing techniques to monitor public attitudes and values associated with wildlife and fish resources to better address the public's needs and wants.

Opportunities to improve resource planning include:

- Increasing interagency cooperation among the many agencies that have responsibility for management of habitat, wildlife and fish populations, and hunting and fishing.
- More fully integrating wildlife and fish management objectives into the management of forest and range lands for multiple resources.
- Through research, improving the information base (e.g., habitat inventories, population inventories, habitat-population relationships, valuation of wildlife and fish resources) needed to effectively manage the wildlife and fish resource.

This review of important management problems, potential management opportunities, and obstacles to effective management indicates that improving the future wildlife and fish resource situation will become an increasingly difficult task. Human populations are expanding and land use is intensifying, yet declining funds for wildlife and fish management is an increasing concern. Unless these trends change, the wildlife and fish profession is faced with the challenging task of solving increasingly complex management problems with a shrinking monetary and personnel resource base. The wildlife and fish management issues and opportunities that could be addressed by future FS programs are discussed in chapter 7.

CHAPTER 7: IMPLICATIONS FOR FOREST SERVICE WILDLIFE AND FISH PROGRAMS

LEGISLATIVE EVOLUTION OF RPA AND THE ASSESSMENT-PROGRAM RELATIONSHIP

The Forest Service (FS) is one of the largest land-managing agencies in the federal government and the natural resources on the lands it administers are important national assets. National forests provide approximately 15% of the total wood volume harvested nationwide, 5% to 10% of the nation's livestock forage, a portion of the nation's energy and mineral resources, 43% of the total recreation visitor-days spent on federal lands, and habitat for approximately 3,000 species of wildlife and fish including critical habitat essential to the survival and recovery of many threatened and endangered species (Barton and Fosburgh 1986, Joyce in press, USDA Forest Service 1987).

Although the multiple benefits associated with FS lands are widely appreciated, the authority to manage the full variety of natural resources on national forests was not legally explicit until 1960 when the Multiple-Use Sustained Yield Act was passed. This Act established the policy that national forests shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes. While the resources to be considered were made explicit, the statute was criticized for being vague on how to reconcile conflicting resource uses (Bean 1977).

The Sikes Act Extension of 1974 further defined the authority to manage wildlife and fish on public lands by directing the Secretaries of Agriculture and the Interior to develop comprehensive plans for the conservation and rehabilitation of wildlife and fish resources in cooperation with state agencies. While the Act facilitated the execution of wildlife and fish management programs, it did little to change the "unlimited discretion" that the FS exercised in fulfilling its multiple use mandates (Bean 1977).

The dispute surrounding multiple use and the allocation of resources was eventually addressed explicitly in the Forest and Rangelands Renewable Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976. These Acts defined a framework to guide long-term planning of natural resources on the nation's forest and rangeland base and required the preparation of a comprehensive *Assessment* that addressed the status and needs of forest and range resources; a *Program* outlining resource management levels and budget requests based on the findings of the assessment; and detailed *Resource Management Plans* for the national forests. The assessment is intended to be the factual and analytical basis for the FS Program. The Program specifies the resource goals "...to enable public and private initiative to meet the full range of opportunities that would secure for our people the benefits..." from the nation's forest and rangelands (Wolf 1982: 139). These goals are to be realized through resource management on national forests, by assisting states and the private sector through forestry assistance programs, and by conducting and promoting research within and outside the FS.

The 1985 Program (USDA Forest Service 1986b) specified the primary agency goal for wildlife and fish management as follows:

> Assure a diverse, well-distributed pattern of habitats for viable populations of wildlife and fish species in cooperation with states and other agencies. Provide technology and manage habitat to help recover threatened and endangered species, and to increase the productivity for native game and nongame species consistent with other resource uses, values, and user demands.

This goal reflected a considerable broadening of the traditional FS wildlife and fish management focus and was a response to increased public interest in wildlife and fish resources. The findings of this wildlife and fish assessment do not suggest that the FS should deviate from this goal. Rather, this assessment emphasizes the need for the agency to promote this broader ecological approach to wildlife and fish management on FS lands.

This chapter summarizes the broad implications of this assessment to the major FS Program areas as they affect wildlife and fish resources.

MAJOR FOREST SERVICE PROGRAMS

The wildlife and fish assessment has direct implications for three FS Program areas:

National Forest System.—Includes the administration and multiple-use management of national forests and national grasslands.

State and Private Forestry.—Includes programs that extend financial and technical assistance to states and private landowners.

Research.—Includes the development of scientific and technical knowledge to enhance the economic and environmental value, and the management of the nation's forest and range resources.

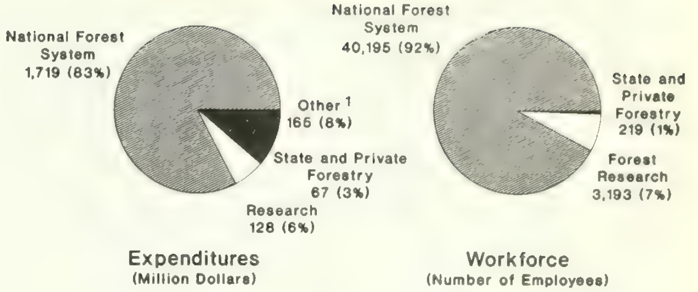
The expenditures and workforce in each of these program areas is concentrated in the National Forest System (NFS) (fig. 62). In fiscal year 1986, the NFS accounted for 83% of the $2.1 billion FS budget and employed over 92% of the FS workforce (USDA Forest Service 1987). The State and Private Forestry Program accounted for just over 3% of the budget and only 0.5% of the workforce. FS Research spent approximately 6% of the budget and employed 7% of the workforce. The broad FS Program implications of the wildlife and fish assessment will be discussed for each of these major program areas.

NATIONAL FOREST SYSTEM

The FS is responsible for the administration of 191 million acres, including 156 national forests (186.4 million acres), 19 national grasslands (3.8 million acres), and a number of smaller land units (275,000 acres) including land-utilization projects, research and experimental areas, and purchase units. Within the lands administered by the FS, wildlife and fish resources are managed primarily through manipulation of habitat while state agencies primarily manage populations and regulate harvests. As implied by the Sikes Act Extension, however, efficient management of wildlife and fish resources requires a close working relationship among agencies with wildlife and fish management responsibility.

The wildlife and fish assessment has implications to the NFS Program in four general areas. These four areas, stated as assessment findings, include:

1. The demand for wildlife and fish recreational activities is expected to increase in the future resulting in a shift in the relative importance of various activities demanded by the public.
2. NFS lands are expected to become more important in: (a) the protection and preservation of certain wildlife and fish species, (b) the preservation and protection of vegetation communities that define important wildlife and fish habitats, and (c) providing wildlife and fish recreational opportunities.



[1]Other consists of Human Resource Programs and Working Capital Fund

Source: USDA, Forest Service (1987)

Figure 62.—Expenditures and workforce by major Forest Service program areas.

3. As demands for all natural resources increase, integration of wildlife and fish management considerations into comprehensive land management plans will become increasingly important.
4. Because wildlife and fish are mobile resources, the purchase and exchange of land that will consolidate land ownership patterns will promote more efficient management of the resource.

Changing Demands for Wildlife and Fish

The national wildlife and fish recreational user projections showed that the relative importance of various activities to the outdoor recreating public is expected to shift. While the number of people participating in nonconsumptive activities, coldwater fishing, and warmwater fishing is expected to increase, participation in big game hunting and small game hunting is expected to decline (see fig. 46). Although participation in all types of wildlife and fish recreational activities is expected to increase on national forests, a similar shift in relative importance is expected. Nonconsumptive recreation and total fishing showed the greatest increases in future use (see table 36). The FS's wildlife and fish habitat management program should acknowledge these findings by shifting priority to management actions that will address those activities demanded by the public.

Increased Importance of National Forest System Lands

As land use intensifies on private lands, NFS lands will become more unique with respect to biotic community composition. Some of the unique wildlife and fish habitats associated with national forests include:

Old-growth forests.—More than half of the remaining old-growth in the Pacific Coast occurred on national forests in 1977; most of the old-growth in the Rocky Mountains occurs on FS lands; current trends indicate that much of the old-growth pine forests in the

South will only be found on national forests or other public ownerships in the future.

Wetlands.—Twenty-five percent of the remaining wetland habitats are under public ownership. The FS has management responsibility for 23% of the federally owned wetlands. Included in the definition of wetland are riparian areas which are a critical wildlife and fish habitat component particularly in arid rangeland ecosystems.

Fish spawning habitat.—Approximately 50% of the anadromous fish spawning and rearing habitat in California, Oregon, Washington, and Idaho is on national forests. In Alaska, 27% of the anadromous fish spawning and rearing habitat is on national forests.

With expanding human populations and increasing demands for multiple resource products from a finite land base, the pressure for intensive management of timber, range, and agricultural resources will remain strong. Consequently, management to conserve these habitat types on national forests will become increasingly important.

Correlated with the uniqueness of certain national forest wildlife and fish habitats are unique faunas. Of particular importance is the maintenance of biotic diversity on national forests (see Norse et al. 1986). The biological diversity issue is, in part, concerned with maintaining the number and kinds of species that exist or have existed on national forests in the recent past. Although maintaining biotic diversity is laudable, methods to quantify, monitor, and anticipate changes in biotic diversity in response to various management activities have not been developed. National forests should establish a process for quantifying and evaluating biological diversity that will permit incorporation of specific diversity objectives in National Forest Plans.

Threatened and endangered species are a special consideration in maintaining diversity. The current distribution of some vanishing species is becoming increasingly associated with NFS lands. Recent estimates indicate that 155 threatened or endangered species occur on national forests, of which 81 have approved recovery plans. However, because of budget and personnel constraints, national forests have emphasized recovery efforts on 13 high-priority species including the grizzly bear, California condor, red-cockaded woodpecker, Kirtland's warbler, woodland caribou, bald eagle, peregrine falcon, Puerto Rican parrot, Lahontan cutthroat and greenback cutthroat trout, and the gray, Indiana, and Virginia big-eared bats.

National forests are also expected to become increasingly important in providing wildlife and fish recreational opportunities. One of the most commonly cited management issues related to recreational use of wildlife and fish was restricted access to private lands (see chapter 6). This has resulted in emphasizing the importance of NFS lands in providing such outdoor recreational opportunities. Specifically, the recreational use projections reviewed in chapter 2 showed that, relative to private lands, national forests are expected to become more important in providing opportunities to hunt b game and small game species.

As national forests become increasingly distincti with respect to habitat, faunal, and recreation opport nities, wildlife and fish management must intensify ensure that the wildlife and fish goal, as outlined in th 1985 FS Program, is met. The FS manages habitat in tw ways: directly, through specific habitat improveme practices, and indirectly, through coordination and mit gation measures in projects designed primarily for oth resources. Direct habitat management, in many case offers the only approach to improve habitat for fis threatened and endangered species, and waterfow (USDA Forest Service 1985b). Some of the opportun ties to directly improve wildlife and fish habitats o national forests to meet future demands include:

1. Expand programs to improve wildlife and fis habitats by increasing food supplies and suitabl cover, improving water quality and availabilit and improving the distribution of habitat.
2. Apply silvicultural and range management prac tices to emphasize management of indicato species.
3. Preserve and enhance waterfowl nesting, migra tion, and wintering habitat.
4. Reintroduce displaced or extirpated species int areas where suitable habitat exists or has bee developed.
5. Increase efforts to define, protect, and improv essential habitats of threatened and endangere species.
6. Remove natural and man-made barriers to fis migration.

Wildlife and Fish Coordination

The second major approach to wildlife and fish habita management on national forests is through coordinatio with management for other resources. In part, these activities are intended to minimize adverse impacts o wildlife and fish habitat from timber harvesting, road building, grazing, mineral development, and other resource projects. However, mitigation is not the only objective of integrating wildlife and fish resource considerations in other resource management activities. When feasible, wildlife and fish coordination efforts are to be designed to generate simultaneous resource benefits. For the wildlife and fish resource, these benefits take the form of indirect habitat improvements.

This assessment, along with associated assessment documents for timber, range, water, recreation and wilderness, and minerals, indicates that there will be increasing demands for multiple resource outputs from national forests. In order to meet these multiple resource demands, coordination among resources must continue as a high priority in wildlife and fish habitat management. Although funding for coordination has commanded the majority of wildlife and fish habitat management budgets in recent years (Barton and Fosburgh 1986), more effective integration of wildlife and fish

resource considerations in multiple use resource plans remains one of the most important management opportunities for wildlife and fish on NFS lands.

One recent advancement directed at improving the integration of wildlife and fish into resource planning is the Wildlife and Fish Habitat Relationships program. The program involves the development of data base management systems and predictive models that permit resource managers to evaluate wildlife and fish responses to a diversity of resource management alternatives. These models have been applied in various situations in providing information for Forest Plans, environmental analyses, and site-specific projects (USDA Forest Service 1987). Further development of the habitat relationships program is required to ensure that the maintenance of wildlife and fish diversity on national forests is considered in the resource planning process.

Consolidation of Land Ownership Patterns

A major management concern for public lands is the difficulty associated with managing a mobile resource over a land base with intermingled and fragmented land ownership (see chapter 6). Most of the larger mammalian and many avian species range widely and independently of ownership boundaries. Consequently, some wildlife and fish resource management can be unsuccessful because of conflicting land uses or conflicting resource management objectives. Potential wildlife and fish management problems associated with NFS lands in a mosaic of state and other federal ownerships can be solved through cooperation among resource managing agencies. However, land ownership patterns characterized by private inholdings, private land surrounding relatively small blocks of national forest, or private ownership of critical habitat components can impede attainment of resource management objectives. In the western United States, land ownership problems tend to be associated with mixed public and private ownership of critical habitat areas. In the East, concern is growing that as private land uses intensify, national forests will become isolated habitat islands with the eventual loss of those species requiring large areas of suitable habitat.

STATE AND PRIVATE FORESTRY

State and Private Forestry provides technical and financial assistance to states to help protect and improve the productivity and management of nonindustrial private forestlands (USDA Forest Service 1987). The Cooperative Forestry Assistance Act of 1978 authorized the Secretary of Agriculture to cooperate with state foresters and provide assistance in a variety of forest-related activities which include fire prevention and control, prevention and control of forest insects and diseases, and forest management and utilization (USDA Forest Service 1987). The latter activity can benefit wildlife through habitat improvement projects.

Private lands have been identified as having considerable potential for wildlife and fish habitat improvement and many investigations have concluded that wildlife and fish resources are considered a primary objective of some private landowners (Barton and Fosburgh 1986). Despite the importance of private lands in providing wildlife and fish habitat and recreational opportunities, the State and Private Forestry Program has recently experienced reductions in funds and personnel. Two findings presented in this assessment suggest that the FS Program should emphasize the importance of the State and Private Forestry activities in promoting effective multiple resource forest management including wildlife and fish resources, particularly in regions dominated by private ownership. These two findings were the projected increase in fee-hunting and the substantial increases in permanent grass and tree cover on private lands associated with the Conservation Reserve Program under the 1985 Food Securities Act.

Fee-hunting and access fees for wildlife and fish recreation on private lands are providing a strong economic incentive for landowners to consider wildlife and fish habitat needs—a consideration that has been absent in the past. Landowners need to be exposed to the full array of products that can be marketed from their land. As reviewed by Sample (1987), the Office of Management and Budget strongly advocates increased efforts to educate landowners about the economic opportunities that exist for their lands, including hunting leases and camping permits. In addition to information on existing markets, landowners need technical assistance on appropriate management practices to improve the quality and sustain productivity of wildlife and fish habitats.

Further support for more intensive education and technical assistance programs stems from the 1985 Food Security Act. Under this Act, substantial acreage of highly erodible cropland will be planted to permanent cover. If planned correctly, these lands can provide high quality wildlife habitat and significantly improve fish habitat through reductions in soil erosion and increased streamside cover. The State and Private Forestry Program has the opportunity to guide and provide assistance on how these lands are managed for multiple forest resources including wildlife and fish. The private landowner has the potential to supplement his income through recreation fees while the nation as a whole can benefit from improved wildlife and fish habitat on lands where there has been a significant eroding of suitable habitat in the recent past.

FOREST SERVICE RESEARCH

The Research Program of the FS is, in general, responsible for the development of scientific and technical knowledge to enhance the economic and environmental values of the nation's forest and rangeland ecosystems (USDA Forest Service 1987). The Program is divided into seven functional areas: Timber Management; Forest Insect and Disease; Forest Products and Harvesting; Forest Fire and Atmospheric Sciences; Forest Environment; Forest Inventory, Economics, and Recreation; and International Forestry. Research in these seven areas is conducted in cooperation with the nation's 61 forestry

schools and through the USDA Cooperative State Research Service.

Today, the dominant authority for Forest Research is the Forest and Rangeland Renewable Resources Research Act of 1978. This legislation revised and consolidated the FS's research authority from several previous Acts. In addition, the Act specifically required that research on natural resources include investigations related to threatened and endangered species and improving wildlife and fish habitat (Barton and Fosburgh 1986). Research related specifically to wildlife and fish is part of Forest Environment Research and is covered under four broad areas: (1) threatened, endangered, and sensitive species; (2) anadromous and coldwater fish habitats; (3) wildlife and fish interactions with livestock; and (4) wildlife and fish interactions with timber management.

In developing future research needs for wildlife and fish, the 1985 Program (USDA Forest Service 1986b) concluded:

> Wildlife and fish habitats will continue to be threatened by urban and suburban development pressures and industrial activities, timber harvesting, livestock grazing, and mining for energy production. Research is needed to: (1) further understand habitat requirements of anadromous and other coldwater fish, determine how their productivity is related to land management, and develop guidelines to integrate production with other resource management issues, and (2) improve wildlife monitoring techniques to measure the response to management.

The knowledge gaps and research needs identified in this assessment support a continuation of this research goal and also suggest a need to broaden future research related to wildlife and fish. As reviewed in chapter 6, information needs identified by federal agency personnel fell into three broad categories: (1) species-habitat relationships, (2) inventory and monitoring techniques, and (3) wildlife and fish values.

Species-habitat relationship research has improved the capability of wildlife and fish resource specialists to understand and predict resource response to land management activities. However, there is a pressing need to test and refine those models that have been developed to ensure that land managers are making reasonable decisions about multiple resource production (Sweeney and Wolters 1986). In addition, new models need to be developed in order for the FS to meet its legislated goal of maintaining biodiversity and habitats capable of supporting viable populations of all native and desired non-native (exotic) species that are found on NFS lands. As the demand for multiple resource outputs from national forests and national grasslands intensifies, accurate representation of wildlife and fish responses to alternative land management strategies will be critical to scientifically-based resource allocation decisions.

Research in the area of improving existing inventory or monitoring methodologies is needed for several reasons. First, inventory information on most of the wildlife and fish species inhabiting national forests does not exist. As discussed in chapter 6, inventory information tends to focus on game animals and selected nongame species of particular concern, yet is generally lacking for all other animal classes. Existing techniques are of questionable accuracy or are too expensive to provide a practicable approach to a comprehensive and systematic inventory of wildlife and fish resources on FS lands. Secondly, further research on population inventory techniques is required to establish the validity of species-habitat relationship models. Although habitat inventories, in conjunction with species-habitat models, may provide great assistance to inventories of the fauna, such faunal inventories will still be required to assess the predictive accuracy of habitat-based models.

A final broad area of research needs concerns the characterization of public attitudes and values held for wildlife and fish resources. The FS must not only monitor the state of wildlife and fish populations and habitat, but it also must monitor the economic values of wildlife and fish. Public demands related to wildlife and fish resources change and methods need to be developed to both measure and anticipate that change. Such information is critical if the FS, or any agency with wildlife and fish stewardship obligations, is to respond to public demands. Quantification of these demands in terms of economic values is critical if wildlife and fish are to compete on an equal basis with other resource elements that are demanded from NFS lands.

In addition to these broad research areas, FS planning requirements under the Renewable Resources Planning Act and National Forest Management Act imply that such research needs to be conducted at a number of geographic scales. These Acts require planning at the national, regional, and national forest level. Research in the areas outlined above must address resource management issues across these planning levels. Risser et al. (1984) summarized the need for multiple-scale resource analyses by concluding that informed resource planning can no longer be based solely at the site level, but must develop methodologies for examining the interaction of resources within landscapes or larger geographic areas. Questions concerning the habitat configurations required by wide-ranging terrestrial species, or the regional ecology of anadromous fish, necessitate an extension of traditional resource management scales to include a landscape ecology research approach.

Some people perceive the FS is at the forefront of fish and wildlife research (Fosburgh 1985b), and this perception should continue in the future by ensuring that the Research Program addresses land management and planning problems facing wildlife and fish resources. Research in the areas outlined above, and across planning scales, will provide a sound basis for meeting the goal of the RPA—namely "... to ensure that the nation achieves the full potential obtainable from its renewable resource base and avoids irreversible crisis in resource use" (Hewett 1982:225).

SUMMARY

The findings of the assessment have wildlife and fish program implications to the NFS, technical and cooperative assistance, and research. Four conclusions have particular importance to wildlife and fish management on national forests. First, the demand for wildlife and fish recreation appears to be shifting away from hunting to fishing and nonconsumptive activities. Such changes should encourage prioritization of those management activities that will address what is demanded by the public. Second, national forests are expected to become more important in the management of certain wildlife and fish habitats and their associated fauna, and in providing wildlife and fish recreational opportunities. For example, old-growth forests are becoming increasingly restricted to national forests; national forests and national grasslands provide critical habitat for threatened and endangered species and they provide increasingly important lands for recreation. Third, as demands for all natural resources increase, integration of wildlife and fish management considerations into the management of other resources will be critical. The wildlife and fish management opportunities considered in conjunction with the opportunities for timber, range, water, recreation and wilderness, and minerals indicate that there will be a need for more intensive and coordinated management if future multiple resource demands are to be met. Fourth, because wildlife and fish are mobile resources, purchase and exchange of land can consolidate land ownership patterns and promote more effective and efficient management of the resource.

This assessment also suggests that the future FS Program should emphasize the importance of technical and cooperative forest management assistance programs in achieving effective wildlife and fish management on private lands. The basis for this conclusion stems from the projected increase in fee-hunting and the substantial increases in permanent grass and tree cover on private lands associated with the Conservation Reserve Program under the 1985 Food Securities Act. Through State and Private Forestry, the FS has the opportunity to guide and provide assistance on how these lands are managed with respect to wildlife and fish resources. The private landowner has the potential to supplement his income through recreation fees while the nation as a whole can benefit from improved wildlife and fish habitat on lands where there has been a significant degradation of suitable habitat in the recent past.

The program implications to NFS's and technical assistance have related implications to wildlife and fish research. The research needs identified in this assessment include development and testing of species-habitat relationship models, improving inventory and monitoring methodologies, and developing techniques to quantify public attitudes and values held for wildlife and fish resources. Research in these areas will improve resource management on both national forests and private lands and will also provide a stronger technical basis for multiple resource planning.

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Anadromous.—Species of fish that mature in the ocean, and then ascend streams to spawn in freshwater.

Animal unit month (AUM).—The amount of forage required for a 1,000 pound cow, or the equivalent, for 1 month.

Archipelago.—Any large body of water with many islands.

Assessment regions.—Regions used in this and other resource assessment documents and include the:

- **Northern**.—Assessment region encompassing the states of Connecticut, Delaware, Iowa, Illinois, Indiana, Massachusetts, Maryland, Maine, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Wisconsin, West Virginia. This includes Forest Service Region 9.
- **Pacific Coast**.—Assessment region encompassing the states of Alaska, California, Hawaii, Oregon, and Washington. This includes Forest Service Regions 5, 6, and 10.
- **Rocky Mountain**.—Assessment region encompassing the states of Arizona, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Utah, and Wyoming. This includes Forest Service Regions 1, 2, 3, and 4.
- **Southern**.—Assessment region encompassing the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. This includes Forest Service Region 8.

Big game.—Large wild animals hunted, or potentially hunted, for sport or food including deer, elk, bear, pronghorn, and wild turkey.

Biotic factors.—Environmental influences caused by plants or animals.

Category 1.—Taxa for which the FWS currently has substantial information to support the biological appropriateness of proposing to list the species as endangered or threatened and the development of proposed rules is anticipated.

Category 2.—Taxa for which information now in the possession of the FWS indicates that proposing to list the species is possibly appropriate but conclusive biological data is not currently available to support development of proposed rules.

Coldwater fishing.—Includes freshwater trout, kokanee, and anadromous fishes such as salmon and steelhead.

Commercial timberland.—Forestland which is producing or capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as commercial timberland have the capability of producing in excess of 20 cubic feet per year of industrial wood in natural stands. Currently, inaccessible and inoperable areas are included.)

Commercial value.—Income derived from the sale or trade of wild animals or their products or from direct and controlled use of wild animals and their progeny.

Community.—A group of populations of plants and animals in a given place; ecological unit used in a broad sense to include groups of various sized and degrees of integration.

Critical habitat.—Air, land, or water area which, if destroyed or degraded, would appreciably decrease the likelihood of survival and recovery of a threatened or endangered species or a segment of its population.

Cropland.—Land under cultivation within the last 24 months including cropland harvested, crop failures, cultivated summer fallow, idle cropland used only for pasture, orchards and land in soil improving crops, but excluding land cultivated in developing improved pasture.

Cumulative impacts.—The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or nonfederal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over time.

Ecological value.—The contribution of wild animals to productive ecosystems.

Ecosystem.—A complete, interacting system of organisms considered together with their environment.

Endangered species.—Any species of animal or plant which is in danger of extinction throughout all or a significant portion of its range. Designated by the U.S. Fish and Wildlife Service.

Estuarine wetlands.—Wetlands found along the U.S. coastline and associated with estuaries or brackish tidal waters.

Existence value.—Valuing an environment regardless of the fact that one may never demand in situ the services it provides.

Exotic.—Foreign; not native.

Flat.—A level landform composed of unconsolidated sediments, usually mud or sand. Flats may be irregularly shaped or elongate and continuous with the shore, whereas bars are generally elongate, parallel to the shore, and separated from the shore by water.

Forest industry lands.—Lands owned by companies or individuals operating wood-using plants.

Forestland.—Land at least 10% stocked by forest trees of any size, or formally having such cover, and not currently developed for other uses.

Forest type.—A category of forest defined by its vegetation (particularly its composition) and/or locality (environmental) factors.

- **Aspen-birch**.—Forests in which aspen, balsam poplar, paper birch, or gray birch, singly or in combination, comprise a plurality of the stocking. (Common associates include maple and balsam fir.)
- **Elm-ash-cottonwood**.—Forest in which elm, ash, or cottonwood, singly or in combination, comprise a plurality of the stocking. (Common associates include willow, sycamore, beech, and maple.)
- **Fir-spruce**.—Forests in which true firs (*Abies* spp.), Engelmann spruce, or Colorado blue spruce, singly or in combination, comprise a plurality of the stocking. (Common associates are mountain hemlock and lodgepole pine.)

Hemlock-Sitka spruce.—Forests in which western hemlock and/or Sitka spruce comprise a plurality of the stocking. (Common associates include Douglas-fir, silver fir, and western redcedar.)

Lodgepole pine.—Forests in which lodgepole pine comprises the stocking. (Common associates include subalpine fir, western white pine, Engelmann spruce, aspen, and larch.)

Maple-beech-birch.—Forests in which 50% or more of the stand is maple, beech, or yellow birch, singly or in combination. (Common associates include hemlock, elm, basswood, and white pine.)

Oak-gum-cypress.—Bottomland forests in which tupelo, blackgum, sweetgum, oaks, or southern cypress, singly or in combination, comprise a plurality of the stocking except where pines comprise 25% to 50% in which case the stand would be classified as oak-pine. (Common associates include cottonwood, willow, ash, elm, hackberry, and maple.)

Oak-hickory.—Forests in which upland oaks or hickory, singly or in combination, comprise a plurality of the stocking except where pines comprise 25% to 50%, in which case the stand would be considered oak-pine. (Common associates include yellow-poplar, elm, maple, and black walnut.)

Oak-pine.—Forest in which hardwoods (usually upland oaks) comprise a plurality of the stocking but in which southern pines comprise 25% to 50% of the stocking. (Common associates include hickory and yellow-poplar.)

Pinyon-juniper.—Forest in which pinyon pine and/or juniper comprise a plurality of the stocking.

Guilds.—A group of species exploiting a common resource base in a similar fashion.

Habitat.—Place where an animal finds the required arrangement of food, cover, and water to meet its biological needs.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Indicator species.—Any species, groups of species, or species habitat elements selected to focus management attention for the purpose of resource production, population recovery, maintenance of population viability, or ecosystem diversity.

Interspecific competition.—Competition between two or more different species.

Juxtaposition.—The minimum geographic interspersion of habitat requirements that must occur if a habitat is to be barely suitable for a species.

Lacustrine wetlands.—Wetlands and deepwater habitats situated in topographic depressions or dammed river channels. Each area must exceed 20 acres or have depths in excess of 2 meters or have an active wave-formed or bedrock shoreline feature.

Migratory birds.—Birds regularly moving seasonally from one region of climate to another for feeding or breeding.

Minimum viable population (MVP).—The number of individuals required to achieve a specific level of viability.

Nominal dollars.—Value of output in a given period in the prices of that period or in current dollars.

Nonconsumptive use.—Activities which do not result in the death or attempted death of an individual animal.

Nongame.—Native vertebrate species that are not consumptively taken for sport, food, fur, or profit.

Nonpoint source pollution.—Pollution that is diffuse in both origin and in time and points of discharge and depend heavily on weather conditions such as rainstorms or snowmelt. Pollutants can originate on natural source areas or on areas affected by man's activities.

Old-growth.—A stand that is past full maturity and showing decadence; the last state in forest succession.

Palustrine emergent wetlands.—Wetlands dominated by herbaceous vegetation including certain grasses, cattails, rushes, and sedges. Often referred to as "marsh," "wet meadow," "fen," and "inland salt marsh."

Palustrine forested wetlands.—Wetlands dominated by trees taller than 20 feet. They occur mostly in the eastern half of the United States and Alaska and include such types as black spruce bogs, cedar swamps, red maple swamps, and bottomland hardwood forests.

Palustrine nonvegetated wetlands.—Wetlands with little or no vegetation other than aquatic beds.

Palustrine open water wetlands.—Small inland open water bodies which are not part of the lacustrine system.

Palustrine scrub-shrub wetlands.—Wetlands dominated by woody vegetation less than 20 feet tall. Commonly referred to as "bog," "pocosin," "shrub-carr," or "shrub swamp."

Palustrine vegetated wetlands.—Broad categorization of wetlands include emergent, scrub-shrub, and forested wetlands.

Palustrine wetlands.—Interior wetlands which largely consist of freshwater, although inland salt and brackish marshes exist in arid and semiarid areas.

Pasture.—Land which is currently improved for grazing by cultivation, seeding, fertilization, or irrigation.

Pelagic.—Occurring in open water and away from the bottom.

Point source pollution.—Any discernible, confined conduit, including pipes, ditches, channels, sewers, tunnels, vessels, and other floating craft from which pollutants are discharged.

Poletimber stands.—Stands at least 10% stocked with growing stock trees of which half or more is sawtimber and/or poletimber trees with poletimber stocking exceeding that of sawtimber.

Population.—A group of individuals of a single species.

Primary nonresidential.—Trips at least 1 mile from place of residence for the primary purpose of observing, photographing, or feeding wildlife.

Primary residential.—Activities around the residence for which primary purpose is wildlife related.

Proposed species.—Species officially proposed for listing by the Fish and Wildlife Service or the National Marine Fisheries Service as threatened or endangered. Designated by the U.S. Fish and Wildlife Service.

Range condition.—The departure of a site's vegetation composition from that expected under the climax plant community.

Rangeland.—Land on which the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs, including land revegetated naturally or artificially that is managed like native vegetation. Rangelands include natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wetlands that are less than 10% stocked with forest trees of any size.

Real dollars.—Attempts to isolate changes in physical output in the economy between time periods by valuing all goods in the two periods at the same prices, or in constant dollars.

Recreational value.—Benefits of pleasure, adventure, and enhanced physical and mental health from outdoor activities involving the pursuit or sometimes accidental enjoyment of wildlife.

Riparian.—The abiotic and biotic components found within the area defined by the banks and adjacent areas of water bodies, water courses, and seeps and springs the waters of which provide soil moisture sufficiently in excess of that otherwise available locally so as to provide a more moist habitat than that of contiguous flood plains, and uplands.

Saplings.—Live trees of commercial species 1.0 inch to 5.0 inches in diameter at breast height and of good form and vigor.

Sawtimber stands.—Stands at least 10% occupied with growing stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

Secondary nonresidential.—Enjoyment from seeing or hearing wildlife on a trip at least 1 mile from place of residence that is taken for another purpose such as camping, driving, or boating.

Secondary residential.—Enjoyment from seeing or hearing wildlife while pursuing other activities around the place of residence.

Seedlings.—Established live trees of commercial species less than 1.0 inch in diameter at breast height and of good form and vigor.

Seedling and sapling stands.—Stands at least 10% occupied with growing stock trees of which more than half of the stocking is saplings and/or seedlings.

Sensitive species.—Species which have been identified by a Forest Service regional forester for which population viability is a concern.

Seral.—Series of stages that follow one another in a usually predictable sequence of ecological succession. Each seral stage is a community with its own characteristics.

Small game.—Smaller-sized wild animals such as rabbits, quail, grouse, and pheasants which are hunted, or potentially hunted, for sport or food. This does not include waterfowl, other migratory birds, and animals generally considered to be pests or varmints.

Snag.—A standing dead tree from which the leaves and most of the limbs have fallen and is more than 20 feet high. Dead trees less than 20 feet are called stubs.

Softwoods.—Coniferous trees, usually evergreen, having needles or scalelike leaves.

Stand-size class.—Classification of forestland based on the predominant size of timber present, that is, sawtimber, poletimber, or seedlings and saplings.

Succession.—Progressive development of a biotic community involving replacement of species and modification of the physical environment until a community with a relatively stable species composition is reached.

Threatened species.—Any species of animal or plant which is likely to become an endangered species within the foreseeable future throughout all or a portion of its range.

User-day.—Any combination of 12 hour days such as one person participating in an activity for 12 hours or 12 persons participating in an activity for 1 hour each.

Urban areas.—Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; school yards, cemeteries, roads, railroads, airports, beaches, powerlines, and other rights-of-way, or other land not included in any other specified land use class.

Viability.—The state of being capable of living, growing, or developing.

Warmwater fishing.—Includes largemouth and smallmouth bass, panfish such as bluegill and crappie, walleye, northern pike, muskie, catfish, bullheads, etc.

Wetlands.—Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil, or (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of the year.

Wilderness.—An area of undeveloped federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticed; (2) has outstanding opportunities for solitude or a primitive and unoccupied type of recreation; (3) has at least 5,000 acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition, and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value (from Wilderness Act 1964).

APPENDIX B: LATIN NAMES

BIRDS	
Bittern, American	*Botaurus lentiginosus*
Bittern, Least	*Ixobrychus exilis*
Bluebird, Eastern	*Sialia sialis*
Bobolink	*Dolichonyx oryzivorus*
Bobwhite, Northern	*Colinus virginianus*
Bobwhite, Masked	*Colinus virginianus ridgwayi*
Bunting, Lark	*Calamospiza melanocorys*
Bunting, Lazuli	*Passerina amoena*
Bunting, Painted	*Passerina ciris*
Canvasback	*Aythya valisineria*
Caracara, Crested	*Caracara plancus*
Cardinal, Northern	*Cardinalis cardinalis*
Chat, Yellow-breasted	*Icteria virens*
Chickadee, Boreal	*Parus hudsonicus*
Chukar	*Alectoris chukar*
Condor, California	*Gymnogyps californianus*
Cormorant	*Phalacrocorax* spp.
Cowbird, Brown-headed	*Molothrus ater*
Crane, Whooping	*Grus americana*
Curlew, Long-billed	*Numenius americanus*
Dickcissel	*Spiza americana*
Dove, Common-Ground	*Columbina passerina*
Dove, Mourning	*Zenaida macroura*
Dove, Rock	*Columba livia*
Duck, American Black	*Anas rubripes*
Duck, Wood	*Aix sponsa*
Eagle, Bald	*Haliaeetus leucocephalus*
Eagle, Southern Bald	*Haliaeetus leucocephalus leucocephalus*
Egret	*Ardeidae*
Egret, Reddish	*Egretta rufescens*
Falcon, Northern aplomado	*Falco femoralis septentrionalis*
Falcon, Peregrine	*Falco peregrinus*
Falcon, Prairie	*Falco mexicanus*
Finch, House	*Carpodacus mexicanus*
Flicker, Northern	*Colaptes auratus*
Flycatcher, Alder	*Empidonax alnorum*
Flycatcher, Olive-sided	*Contopus borealis*
Flycatcher, Scissor-tailed	*Tyrannus forficatus*
Flycatcher, Willow	*Empidonax traillii*
Gadwall	*Anas strepera*
Goldfinch, American	*Carduelis tristis*
Goose, Aleutian Canada	*Branta canadensis leucapareia*
Goose, Cackling	*Branta canadensis minima*
Goose, Dusky Canada	*Branta canadensis occidentalis*
Grosbeak, Black-headed	*Pheucticus melanocephalus*
Grouse, Blue	*Dendragapus obscurus*
Grouse, Ruffed	*Bonasa umbellus*
Grouse, Sage	*Centrocercus urophasianus*
Grouse, Sharp-tailed	*Tympanuchus phasianellus*
Grouse, Spruce	*Dendragapus canadensis*
Gull, Franklin's	*Larus pipixcan*
Harrier, Northern	*Circus cyaneus*
Hawk, Cooper's	*Accipiter cooperii*
Hawk, Ferruginous	*Buteo regalis*
Hawk, Sharp-shinned	*Accipiter striatus*
Heron	*Ardeidae*
Heron, Little blue	*Egretta caerulea*
Ibis	*Threskiornithidae*

BIRDS

Jay, Blue	*Cyanocitta cristata*
Jay, Gray	*Perisoreus canadensis*
Junco, Dark-eyed	*Junco hyemalis*
Kingfisher, Belted	*Ceryle alcyon*
Kinglet, Ruby-crowned	*Regulus calendula*
Kite, Snail	*Rostrhamus sociabilis*
Lark, Horned	*Eremophila alpestris*
Mallard	*Anas platyrhynchos*
Meadowlark, Eastern	*Sturnella magna*
Meadowlark, Western	*Sturnella neglecta*
Merlin	*Falco columbarius*
Mockingbird, Northern	*Mimus polyglottos*
Oriole, Orchard	*Icterus spurius*
Osprey	*Pandion haliaetus*
Owl, Burrowing	*Athene cunicularia*
Owl, Great Horned	*Bubo virginianus*
Owl, Screech	*Otus* spp.
Owl, Spotted	*Strix occidentalis*
Parrot, Thick-billed	*Rhynchopsitta pachyrhyncha*
Parrot, Puerto Rican	*Amazona vittata*
Pelican, Brown	*Pelecanus occidentalis*
Pheasant, Ring-necked	*Phasianus colchicus*
Phoebe, Eastern	*Sayornis phoebe*
Pintail, Northern	*Anas acuta*
Plover, Snowy	*Charadrius alexandrinus*
Prairie-Chicken, Greater	*Tympanuchus cupido*
Ptarmigan	*Lagopus* spp.
Quail, California	*Callipepla californica*
Quail, Gambel's	*Callipepla gambelii*
Quail, Mountain	*Oreortyx pictus*
Quail, Scaled	*Callipepla squamata*
Rail, Black	*Laterallus jamaicensis*
Redhead	*Aythya americana*
Robin, American	*Turdus migratorius*
Sandpiper, Upland	*Bartramia longicauda*
Sapsucker, Yellow-bellied	*Sphyrapicus varius*
Scaup	*Aythya* spp.
Shoveler, Northern	*Anas clypeata*
Shrike, Loggerhead	*Lanius ludovicianus*
Snipe, Common	*Gallinago gallinago*
Sparrow, Baird's	*Ammodramus bairdii*
Sparrow, Black-throated	*Amphispiza bilineata*
Sparrow, Chipping	*Spizella passerina*
Sparrow, Field	*Spizella pusilla*
Sparrow, Grasshopper	*Ammodramus savannarum*
Sparrow, Henslow's	*Ammodramus henslowii*
Sparrow, House	*Passer domesticus*
Sparrow, Lark	*Chondestes grammacus*
Sparrow, LeConte's	*Ammodramus leconteii*
Sparrow, Savannah	*Passerculus sandwichensis*
Sparrow, Song	*Melospiza melodia*
Sparrow, Vesper	*Pooecetes gramineus*
Sparrow, White-throated	*Zonotrichia albicollis*
Starling, European	*Sturnus vulgaris*
Swallow, Barn	*Hirundo rustica*
Swallow, Cliff	*Hirundo pyrrhonota*
Swan, Trumpeter	*Cygnus buccinator*
Tanager, Western	*Piranga ludoviciana*
Teal, Blue-winged	*Anas discors*
Teal, Green-winged	*Anas crecca*

BIRDS	
Tern, Gull-billed	*Sterna nilotica*
Tern, Roseate	*Sterna dougallii*
Thrasher, Curve-billed	*Toxostoma curvirostre*
Thrush, Wood	*Hylocichla mustelina*
Titmouse, Tufted	*Parus bicolor*
Towhee, Rufous-sided	*Pipilo erythrophthalmus*
Turkey, Wild	*Meleagris gallopavo*
Veery	*Catharus fuscescens*
Verdin	*Auriparus flaviceps*
Vireo, Bell's	*Vireo bellii*
Vireo, Red-eyed	*Vireo olivaceus*
Vireo, Warbling	*Vireo gilvus*
Warbler, Bachman's	*Vermivora bachmanii*
Warbler, Blue-winged	*Vermivora pinus*
Warbler, Golden-cheeked	*Dendroica chrysoparia*
Warbler, Kirtland's	*Dendroica kirtlandii*
Warbler, Nashville	*Vermivora ruficapilla*
Warbler, Pine	*Dendroica pinus*
Warbler, Prairie	*Dendroica discolor*
Warbler, Prothonotary	*Protonotaria citrea*
Warbler, Tennessee	*Vermivora peregrina*
Warbler, Worm-eating	*Helmitheros vermivorus*
Wigeon, American	*Mareca americana*
Woodcock, American	*Scolopax minor*
Woodpecker, Ivory-billed	*Campephilus principalis*
Woodpecker, Pileated	*Dryocopus pileatus*
Woodpecker, Red-cockaded	*Picoides borealis*
Wood-Pewee	*Contopus* spp.
Wren, Bewick's	*Thryomanes bewickii*
Wren, Cactus	*Campylorhynchus brunneicapillus*
Wren, Carolina	*Thryothorus ludovicianus*
Wren, Sedge	*Cistothorus platensis*
Wren, Winter	*Troglodytes troglodytes*
MAMMALS	
Bat, Gray	*Myotis grisescens*
Bat, Indiana	*Myotis sodalis*
Bat, Virginia big-eared	*Plecotus townsendii virginianus*
Bear, Black	*Ursus americanus*
Bear, Grizzly	*Ursus arctos*
Beaver	*Castor canadensis*
Bison also Buffalo	*Bison bison*
Boar, also European wild	*Sus scrofa*
Bobcat	*Lynx rufus*
Caribou, Woodland	*Rangifer tarandus caribou*
Cottontail	*Sylvilagus* spp.
Coyote	*Canis latrans*
Deer	*Odocoileus* spp.
Deer, Black-tailed	*Odocoileus hemionus columbianus*
Deer, Columbian white-tailed	*Odocoileus virginianus columbianus*
Deer, Key	*Odocoileus virginianus clavium*
Deer, Mule	*Odocoileus hemionus*
Deer, Desert Mule	*Odocoileus hemionus crooki*
Deer, Sitka black-tailed	*Odocoileus hemionus sitkensis*
Deer, White-tailed	*Odocoileus virginianus*
Elk	*Cervus elaphus*
Ferret, Black-footed	*Mustela nigripes*
Fox, Gray	*Urocyon cinereoargenteus*

MAMMALS

Fox, Northern Swift	*Vulpes velox hebes*
Fox, Red	*Vulpes vulpes*
Fox, San Joaquin Kit	*Vulpes macrotis mutica*
Goat, Mountain	*Oreamnos americanus*
Gopher, Pocket	*Geomyidae*
Hare	*Lepus* spp.
Jackrabbit	*Lepus* spp.
Jackrabbit, Black-tailed	*Lepus californicus*
Jackrabbit, White-tailed	*Lepus townsendii*
Jaguarundi	*Felis yagouaroundi*
Javelina	*Dicotyles tajacu*
Lion, Mountain	*Felis concolor*
Lynx	*Lynx candensis*
Manatee	*Trichechus manatus*
Marmot, Yellow-bellied	*Marmota flaviventris*
Mink	*Mustela vison*
Moose	*Alces alces*
Mouse, House	*Mus musculus*
Muskrat	*Ondatra zibethicus*
Nutria	*Myocastor coypus*
Ocelot	*Felis pardalis*
Opossum, Virginia	*Didelphus virginiana*
Otter, Sea	*Enhydra lutris*
Panther, Florida	*Felis concolor coryi*
Peccary, Collared	*Tayassu tajacu*
Pig	*Sus scrofa*
Pika	*Ochotona princeps*
Prairie Dog	*Cynomys* spp.
Prairie Dog, Utah	*Cynomys parvidens*
Pronghorn	*Antelocapra americana*
Pronghorn, Sonoran	*Antelocapra americana sonoriensis*
Raccoon	*Procyon lotor*
Rat, Giant Kangaroo	*Dipodomys ingens*
Rat, Kangaroo	*Dipodomys* spp.
Rat, Norway	*Rattus norvegicus*
Ringtail	*Bassariscus astutus*
Sheep, Bighorn	*Ovis canadensis*
Sheep, Dall	*Ovis dalli*
Sheep, Desert bighorn	*Ovis canadensis merriam*
Skunk	*Mustelidae*
Squirrel	*Sciurus* spp.
Squirrel, Fox	*Sciurus niger*
Squirrel, Gray	*Sciurus carolinensis*
Squirrel, Northern flying	*Glaucomys sabrinus*
Wolf, Gray	*Canis lupus*
Wolf, Eastern Timber	*Canis lupus lycaon*
Wolf, Red	*Canis rufus*
Wolf, Texas red	*Canis rufus rufus*
Wolverine	*Gulo gulo*

FISH

Alewife	*Alosa pseudoharengus*
Bass, Largemouth	*Micropterus salmoides*
Bass, Smallmouth	*Micropterus dolomieui*
Bass, Striped	*Morone saxatilis*
Bass, White	*Morone chrysops*
Buffalo	*Ictiobus* spp.
Bullhead	*Ictalurus* spp.
Carp	*Cyprinus carpio*
Catfish	*Ictalurus* spp.

FISH

Catfish, Walking	*Clarias batrachus*
Chubs	*Coregonus* spp.
Crappie	*Pomixis annularis*
	Pomixis nigromaculatus
Gar	*Lepisosteus* spp.
Paddlefish	*Polyodon spathula*
Perch, White	*Morone americana*
Perch, Yellow	*Perca flavescens*
Pickerel	*Esox* spp.
Pike	*Esox* spp.
Salmon, Chinook	*Oncorhynchus tshawytscha*
Salmon, Chum	*Oncorhynchus keta*
Salmon, Coho	*Oncorhynchus kisutch*
Salmon, Pink	*Oncorhynchus gorbuscha*
Salmon, Sockeye	*Oncorhynchus nerka*
Sauger	*Stizostedion canadense*
Shad	*Alosa sapidissima*
Shad, Gizzard	*Dorosoma cepedianum*
Sheepshead	*Aplodinotus grunniens*
Smelt	*Osmeridae*
Suckers	*Catostomidae*
Trout, Greenback cutthroat	*Salmo clarki stomias*
Trout, Lahontan cutthroat	*Salmo clarki henshawi*
Trout, Steelhead	*Salmo gairdneri*
Tullibee	*Coregonus* spp.
Walleye	*Stizostedion vitreum*
Whitefish	*Coregonus* spp.

REPTILES

Crocodile, American	*Crocodylus acutus*
Hawksbill	*Eretmochelys imbricata*
Tortoise, Desert	*Gopherus agassizii*
Turtle, Ridley Sea	*Lepidochelys* spp.
Rattlesnake, New Mexico ridge-nosed	*Crotalus willardi obscurus*

CRUSTACEANS

Crab, Blue	*Callinectes* spp.
Crab, King	*Paralithodes camschatica*
	Paralithodes platypus
	Lithodes acquispina
Crab, Snow	*Chionoecetes bairdi*

PLANTS[1]

Alder, Red	*Alnus rubra*
Aspen	*Populus* spp.
Beech	*Fagus grandifolia*
Creosote	*Larrea tridentata*
Elm	*Ulmus* spp.
Fir, Douglas	*Pseudotsuga menziesii*
Larch	*Larix* spp.
Maple	*Acer* spp.
Maple, Red	*Acer rubrum*
Mesquite	*Prosopis juliflora*
Pine, Lodgepole	*Pinus contorta*
Pine, Ponderosa	*Pinus ponderosa*
Pine, Western white	*Pinus monticola*
Redwood	*Sequoia sempervirens*
Sweetgum	*Liquidambar styraciflua*
Sycamore	*Platanus* spp.
Tupelo	*Nyssa* spp.

[1] *For a complete list of plants associated with forage and range ecosystems, refer to Joyce (in press).*

APPENDIX C: TRENDS IN WILDLIFE AND FISH POPULATIONS, USE, AND HARVEST ON NATIONAL FOREST SYSTEM LANDS

Table C-1.—Trends in selected big game populations on NFS lands in the North.

Year	Moose	Deer	Gray wolf	Black bear	Turkey
1965	3,920	467,000	900	11,800	38,200
1966	4,100	414,000	620	11,000	20,000
1967	4,300	442,000	800	10,000	21,000
1968	4,200	396,000	360	8,100	24,000
1969	4,000	363,000	360	9,100	29,000
1970	3,800	338,000	450	8,800	18,000
1971	3,800	304,000	450	7,600	21,000
1972	4,800	297,000	520	8,300	31,000
1973	5,100	281,000	480	8,900	29,000
1974	5,200	298,000	480	8,900	28,000
1975	2,200	312,000	420	8,900	29,000
1976	2,500	290,000	600	9,400	30,000
1977	3,000	323,000	580	8,600	33,000
1978	2,710	314,114	574	9,547	42,656
1979	3,320	307,985	322	16,659	44,933
1980	3,245	315,109	378	9,226	50,772
1981	3,780	320,512	347	10,820	50,017
1982	5,485	317,962	348	10,070	39,384
1983	6,978	318,042	348	12,097	39,438
1984	6,589	326,619	345	11,800	34,319

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-2.—Trends in selected big game populations on NFS lands in the South.

Year	Deer	Turkey	Black bear	Wild (feral) pig
1965	248,000	41,800	3,100	1,300
1966	265,000	52,000	3,800	1,400
1967	277,000	55,000	4,000	1,600
1968	289,000	57,000	4,000	1,600
1969	280,000	59,000	3,400	1,400
1970	284,000	69,000	2,700	860
1971	285,000	74,000	3,100	1,500
1972	303,000	85,000	2,800	2,500
1973	286,000	81,000	2,900	2,400
1974	307,000	85,000	2,500	2,600
1975	306,000	77,000	2,600	2,000
1976	309,000	82,000	2,600	2,200
1977	301,000	86,000	2,800	2,500
1978	303,060	95,382	2,853	2,282
1979	289,280	104,662	3,230	1,522
1980	298,330	111,185	4,015	1,710
1981	279,886	115,866	3,958	1,525
1982	265,164	122,730	2,432	1,684
1983	275,526	124,133	3,027	1,954
1984	280,504	123,187	3,722	2,415

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-3.—Trends in selected big game populations on NFS lands in the Rocky Mountains.

Year	Moose	Pronghorn	Elk	Peccary	Mountain lion	Turkey	Deer	Mountain goat	Bighorn sheep	Caribou	Bear
1965	12,250	47,100	268,000	24,000		75,400	1,742,100	9,990	11,533	140	44,800
1966	12,400	42,700	266,000	27,000		84,400	1,609,200	10,330	11,343	140	46,105
1967	12,990	40,600	280,000	28,000		81,800	1,642,900	10,490	12,237	100	46,200
1968	12,770	34,900	263,000	22,000		69,000	1,617,600	9,670	10,825	115	44,125
1969	11,450	34,900	270,000	24,000		69,000	1,612,100	9,670	10,825	85	43,930
1970	13,640	32,900	274,000	21,000		66,900	1,595,900	9,720	11,000	85	43,630
1971	13,400	34,900	275,000	21,000		65,300	1,560,900	9,360	11,190	90	43,560
1972	14,020	37,800	276,000	21,000		53,600	1,518,900	9,340	11,480	80	45,390
1973	13,970	34,500	272,300	20,000	5,000	55,200	1,184,700	8,910	11,680	70	43,591
1974	14,820	38,900	282,000	21,000	5,540	56,100	1,352,200	8,640	11,870	60	43,570
1975	15,300	41,500	292,000	21,000	5,390	54,800	1,219,950	8,260	12,900	45	43,025
1976	15,770	39,900	293,000	21,000	5,670	52,400	1,102,930	7,280	13,130	45	43,415
1977	15,700	44,800	323,000	21,000	6,030	52,600	1,120,680	7,900	13,790	40	42,220
1978	16,027	54,789	307,989	20,183	6,288	54,617	1,118,451	8,242	14,334	41	40,840
1979	16,091	43,332	302,443	19,273	6,197	55,205	1,097,746	7,592	15,016	30	41,670
1980	16,640	43,379	298,404	21,277	6,452	57,702	1,099,797	8,067	15,757	30	42,835
1981	16,504	42,747	332,573	22,187	6,776	57,456	1,198,656	8,086	16,936	25	43,931
1982	15,987	45,275	346,783	23,746	7,027	59,105	1,289,533	7,713	17,512	15	41,247
1983	15,722	54,464	362,593	24,701	7,320	61,363	1,238,384	7,650	17,586	20	42,157
1984	15,566	52,704	371,759	25,783	7,608	65,689	1,197,102	7,915	17,658	17	44,552

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-4.—Trends in selected big game populations on NFS lands in the Pacific Coast.

Year	Moose	Pronghorn	Gray wolf	Elk	Turkey	Deer	Mountain goat	Bighorn sheep	Caribou	Bear
1965	4,515	3,000	1,900	92,820	2,710	1,564,900	21,800	2,015	6	55,301
1966	4,720	3,100	1,800	91,050	3,600	1,511,900	20,400	2,390	10	56,300
1967	3,920	3,000	2,000	94,250	3,400	1,633,100	20,100	3,460	50	54,303
1968	5,020	3,000	2,300	87,540	4,200	1,535,700	21,300	3,500	60	53,404
1969	5,316	3,400	2,100	90,400	4,600	1,436,300	20,800	2,980	75	51,102
1970	6,415	4,000	2,102	87,900	5,000	1,392,000	20,900	2,715	40	52,102
1971	5,615	4,200	2,100	90,500	4,900	1,316,000	20,200	2,440	170	50,002
1972	6,015	4,100	1,400	92,100	5,200	1,172,900	20,000	2,590	200	47,002
1973	5,620	4,700	1,004	93,600	5,300	1,045,600	20,000	2,630	280	43,620
1974	5,400	3,600	804	103,700	4,900	1,035,000	19,000	2,590	300	43,912
1975	4,618	4,300	800	104,700	4,200	972,000	18,100	2,560	355	46,003
1976	4,518	4,700	750	107,900	4,400	999,000	15,900	2,630	355	46,702
1977	4,630	5,300	702	107,190	3,900	980,000	16,300	3,310	355	45,004
1978	4,586	5,181	700	106,931	6,318	1,042,222	16,387	3,412	355	45,289
1979	4,492	5,320	825	102,864	5,773	972,035	13,929	3,236	355	48,149
1980	4,901	5,457	825	96,599	6,514	955,724	13,760	3,279	255	47,052
1981	4,853	5,482	842	95,298	6,798	991,747	14,179	2,937	255	46,956
1982	5,298	5,506	867	100,817	6,934	1,031,711	13,711	3,663	503	48,591
1983	4,925	5,217	767	99,605	7,386	981,992	15,651	3,762	6	40,804
1984	4,091	5,376	817	93,853	8,144	933,556	17,237	2,744	306	46,406

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-5.—National and regional trends in nonconsumptive user days on NFS lands.

Year	National	North	Rocky South	Pacific Mountain	Coast
1980	1,342,500	120,000	150,800	525,000	546,700
1981	1,550,770	127,100	205,600	633,600	584,400
1982	1,474,500	114,300	194,300	591,900	574,000
1983	1,277,400	115,700	179,900	537,100	444,700
1984	1,277,700	106,400	200,000	536,500	434,800

Source: USDA Forest Service (1980–1985).

Table C-6.—Trends in migratory bird user-days on NFS lands by assessment region.

Year	National	North	South	Rocky Mountain	Pacific Coast
1966	649,000	199,000	113,000	161,000	176,000
1967	614,000	188,000	113,000	158,000	155,000
1968	573,000	188,000	94,000	136,000	155,000
1969	574,000	201,000	94,000	127,000	152,000
1970	585,000	198,000	86,000	129,000	172,000
1971	621,000	232,000	90,000	147,000	152,000
1972	675,000	231,000	96,000	173,000	175,000
1973	657,000	229,000	92,000	163,000	173,000
1974	769,500	242,200	122,800	194,400	210,100
1975	775,300	276,400	117,400	183,100	198,400
1976	757,700	272,300	112,800	160,900	211,700
1977	813,900	232,600	111,700	222,300	247,300
1978	818,100	242,000	111,700	203,500	260,900
1979	801,500	241,800	118,000	209,800	231,900
1980	723,100	226,500	117,100	205,800	173,700
1981	796,700	234,500	123,000	222,200	217,000
1982	757,600	201,800	128,000	215,800	212,000
1983	613,700	198,600	122,700	197,200	95,200
1984	578,800	188,300	100,200	196,300	94,000

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-7.—Big game user-days on national forests by assessment region.

Year	National	North	South	Rocky Mountain	Pacific Coast
1966	9,916,000	963,000	1,871,000	4,007,000	3,075,000
1967	9,253,000	1,059,000	1,400,000	3,831,000	2,963,000
1968	9,449,000	1,083,000	1,535,000	3,725,000	3,106,000
1969	10,034,000	1,072,000	1,593,000	4,043,000	3,326,000
1970	10,075,000	1,123,000	1,550,000	4,072,000	3,330,000
1971	10,032,000	1,030,000	1,747,000	4,106,000	3,149,000
1972	9,076,000	781,000	1,818,000	3,787,000	2,690,000
1973	9,373,000	889,000	1,836,000	4,012,000	2,636,000
1974	9,742,500	917,100	1,818,000	4,105,200	2,902,200
1975	9,813,400	1,014,400	1,877,600	4,101,400	2,820,000
1976	9,415,300	1,129,300	1,855,500	3,677,200	2,753,300
1977	9,738,000	1,236,500	1,951,900	3,961,200	2,588,400
1978	9,632,700	1,223,500	1,934,200	3,673,000	2,802,000
1979	10,186,400	1,218,500	2,023,000	4,138,900	2,806,000
1980	10,445,800	1,333,400	1,960,600	4,111,600	3,040,200
1981	10,875,200	1,354,400	2,091,000	4,584,600	2,845,200
1982	10,875,900	1,296,500	2,120,800	4,520,300	2,938,300
1983	11,148,100	1,345,000	2,130,100	4,697,900	2,975,100
1984	10,612,000	1,222,500	2,006,600	4,561,800	2,821,100

Source: USDA Forest Service (1966–1984).

Table C-8.—Trends in small game user-days on the national forests by assessment region.

Year	National	North	South	Rocky Mountain	Pacific Coast
1965	3,891,000	1,075,000	1,202,000	546,000	350,000
1966	3,535,000	924,000	1,405,000	706,000	500,000
1967	3,252,000	866,000	1,271,000	620,000	495,000
1968	3,227,000	792,000	1,343,000	590,000	501,800
1969	3,436,000	897,000	1,423,000	594,000	522,000
1970	3,488,000	880,000	1,480,000	617,000	511,000
1971	3,646,000	920,000	1,575,000	635,000	516,000
1972	3,378,000	768,000	1,592,000	593,000	425,000
1973	3,713,000	948,000	1,664,000	638,000	469,000
1974	3,719,000	956,000	1,593,500	678,100	491,400
1975	3,834,100	1,015,200	1,635,800	686,500	496,600
1976	3,899,400	1,090,400	1,612,500	664,300	532,200
1977	3,965,100	1,031,600	1,690,900	746,100	496,500
1978	4,195,400	1,042,300	1,729,100	807,500	616,500
1979	4,340,000	1,007,500	1,792,800	866,000	673,700
1980	4,711,000	1,279,400	1,925,300	914,100	592,200
1981	4,741,100	1,180,700	1,906,300	1,044,600	609,500
1982	4,601,700	1,113,700	1,807,100	1,019,600	661,300
1983	4,367,300	1,101,100	1,757,100	951,000	557,500
1984	4,056,500	984,200	1,690,300	882,500	498,700

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-9.—Warm- and coldwater fishing user-days on national forests, by region.

Year	National		North		South		Rocky Mountain		Pacific Coast	
	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
1967	2,457,000	12,248,000	904,000	686,000	1,154,000	596,000	291,000	4,973,000	108,000	5,993,000
1968	2,385,000	11,530,000	807,000	609,000	1,196,000	541,000	254,000	4,806,000	128,000	5,574,000
1969	2,862,000	11,554,000	1,141,000	662,000	1,275,000	571,000	311,000	4,982,000	135,000	5,339,000
1970	3,019,000	11,751,000	1,294,000	579,000	1,281,000	595,000	306,000	4,979,000	138,000	5,598,000
1971	3,188,000	11,917,000	1,353,000	646,000	1,334,000	582,000	230,000	5,156,000	271,000	5,533,000
1972	3,102,000	11,600,000	1,072,000	623,000	1,391,000	619,000	243,000	5,205,000	396,000	5,153,000
1973	3,314,000	12,000,000	1,125,000	619,000	1,433,000	672,000	360,000	5,444,000	396,000	5,265,000
1974	3,568,700	12,021,300	1,404,000	690,600	1,422,600	776,600	337,900	5,338,900	404,200	5,218,200
1975	4,432,200	11,783,800	1,601,800	661,100	2,095,800	741,800	373,100	5,196,800	361,500	5,184,100
1976	4,152,800	11,772,800	1,352,400	705,400	2,053,600	735,600	389,400	5,186,400	357,400	5,145,400
1977	3,894,200	11,834,700	1,335,300	680,200	2,194,900	690,600	226,000	6,123,100	138,000	4,340,800
1978	4,118,500	12,059,200	1,384,500	698,600	2,181,800	723,200	265,600	5,870,400	286,600	4,767,000
1979	3,937,700	11,649,500	1,231,400	625,300	2,126,200	799,800	293,400	5,959,100	286,700	4,825,300
1980	4,328,800	12,358,600	1,330,500	622,100	2,327,700	823,100	331,500	6,027,500	339,100	4,885,900
1981	4,096,400	12,402,300	1,389,200	640,400	2,047,900	798,300	326,900	6,215,200	332,400	4,748,400
1982	4,089,400	11,989,100	1,387,200	664,100	2,034,800	774,500	324,900	5,898,300	342,500	4,561,200
1983	4,119,400	11,402,600	1,428,100	658,000	2,010,900	764,600	282,800	5,371,700	397,600	4,248,300
1984	4,046,700	11,125,600	1,327,600	639,500	1,966,900	787,400	351,100	5,365,800	401,100	4,332,900

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-10.—Harvest trends for selected big game species on NFS lands in the North.

Year	Deer	Turkey	Black bear
1965	62,000	450	760
1966	66,000	2,100	900
1967	60,000	1,700	970
1968	68,000	2,100	650
1969	62,000	2,100	890
1970	54,000	2,900	850
1971	41,000	3,100	760
1972	29,000	3,600	770
1973	37,000	3,300	730
1974	39,000	4,200	650
1975	43,000	3,600	670
1976	44,000	4,600	790
1977	45,000	4,100	760
1978	51,597	5,217	1,147
1979	53,900	4,895	1,268
1980	54,329	5,596	1,262
1981	54,484	7,675	1,278
1982	60,607	7,444	1,356
1983	56,564	7,377	1,255
1984	61,348	4,291	1,401

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-11.—Harvest trends for selected game species on NFS lands in the South.

Year	Deer	Turkey	Black bear
1965	20,000	2,300	230
1966	32,000	4,800	370
1967	32,000	5,500	420
1968	34,000	4,700	500
1969	32,000	5,800	560
1970	33,000	6,800	310
1971	36,000	7,200	370
1972	36,000	6,600	310
1973	34,000	6,000	300
1974	36,000	6,900	300
1975	39,000	5,400	210
1976	41,000	6,400	230
1977	41,000	6,800	330
1978	39,739	7,969	264
1979	39,705	9,552	310
1980	41,908	11,241	359
1981	41,859	11,605	310
1982	45,728	10,816	282
1983	49,120	11,569	364
1984	48,788	10,432	450

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-12.—Harvest trends in selected big game species on NFS lands in the Rocky Mountains.

Year	Moose	Pronghorn	Elk	Pecarry	Mountain lion	Turkey	Deer	Mountain goat	Bighorn sheep	Black bear
1965	1,450	10,670	50,100	2,300		6,450	295,470	624	380	4,849
1966	1,420	7,900	47,000	2,900		6,805	342,230	604	365	4,734
1967	1,530	7,490	50,400	3,800		6,380	294,520	588	316	5,103
1968	1,610	7,340	50,800	4,600		5,650	309,000	620	362	4,730
1969	1,590	6,930	57,800	3,000		4,910	325,860	615	370	5,301
1970	1,380	5,940	61,500	3,400		3,886	300,570	600	286	4,616
1971	1,570	6,290	58,400	3,000		4,170	298,160	550	380	4,453
1972	1,725	6,260	50,800	2,600		5,500	254,480	517	290	4,451
1973	1,911	6,480	53,500	2,300	522	3,660	243,600	480	298	4,178
1974	2,050	6,840	63,600	2,500	579	4,985	228,990	540	357	4,056
1975	1,950	7,480	12,000	2,300	680	4,415	191,450	460	80	918
1976	2,050	8,270	63,600	2,500	700	6,030	159,245	380	409	4,621
1977	1,740	9,070	55,400	3,000	660	4,670	140,540	420	399	4,362
1978	2,036	9,790	60,753	2,148	691	4,724	170,753	409	402	4,406
1979	1,815	7,852	58,194	2,595	652	5,335	177,301	376	448	4,341
1980	1,840	5,724	60,108	2,608	649	6,126	169,118	394	505	4,300
1981	1,663	5,814	58,204	3,742	619	6,024	177,557	361	505	4,655
1982	1,716	7,252	64,985	3,506	741	6,975	203,055	347	528	4,003
1983	1,609	9,307	65,824	3,865	936	7,406	191,309	263	596	3,995
1984	1,396	10,716	64,172	3,671	862	7,038	212,130	280	682	4,377

Source: USDA Forest Service (1965–1977, 1978–1985).

Table C-13.—Harvest trends in selected big game species on NFS lands in the Pacific Coast.

Year	Moose	Pronghorn	Gray wolf	Elk	Mountain lion	Turkey	Deer	Mountain goat	Bighorn sheep	Caribou	Black bear
1965	760	90	280	18,060		0	133,420	800	10	0	3,560
1966	470	110	230	14,300		36	109,200	660	25		4,030
1967	340	90	240	16,120		30	141,280	880	40	0	3,901
1968	470	110	290	13,120		90	126,680	770	38	0	3,510
1969	730	90	230	13,100		80	143,500	850	56	0	3,430
1970	840	120	240	13,160		40	105,800	900	57	0	3,660
1971	750	130	250	15,090		60	96,820	800	79	0	2,690
1972	720	220	210	11,040		85	77,290	690	24	0	3,040
1973	500	300	92	11,915	143	235	61,560	920	23	6	3,160
1974	410	270	65	14,018	73	80	72,060	770	25	12	3,020
1975	210	220	100	15,031	121	90	65,000	800	25	40	3,280
1976	161	185	120	17,025	102	90	69,700	640	12	85	3,170
1977	161	370	80	15,030	120	100	63,100	610	13	80	3,090
1978	217	329	77	18,923	146	110	97,246	550	18	27	2,971
1979	327	263	110	18,077	169	122	83,085	605	57	30	3,117
1980	115	284	81	16,689	152	127	77,507	639	25	33	3,108
1981	295	274	88	21,288	138	177	81,526	537	28	38	3,086
1982	371	296	98	18,619	167	189	91,887	510	26	42	2,975
1983	375	305	87	18,188	127	189	68,621	638	32	0	2,795
1984	365	315	147	15,772	111	186	68,590	620	38	42	2,740

Source: USDA Forest Service (1965–1977, 1978–1985).

☆U.S. GOVERNMENT PRINTING OFFICE: 1989-676-566

Forest Service Regions and Assessment Regions

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-179**

An Analysis of the Minerals Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
General Technical Report RM-179

September 1989

An Analysis of the Minerals Situation in the United States: 1989–2040

ACKNOWLEDGMENTS

Though prepared by the Resources Program and Assessment Staff, a number of people contributed to this Analysis of the Minerals Situation in the United States: 1989–2040. William E. Shands and Lisa Fernandez of The Conservation Foundation served as contributing editors to the volume. Buster LaMoure, Director, and Floyd Deloney and Tom King, of the Forest Service Minerals and Geology Management Staff provided information on Forest Service minerals activity. Thanks are due to many specialists in the Department of Interior's Bureau of Mines and personnel at the Department of Energy for providing information on minerals supply and demand.

Contents

An Analysis of the Minerals Situation in the United States: 1989–2040

INTRODUCTION

Highlights

- Minerals are essential to modern life.
- Minerals are important to the national economy and the economies of many states.
- Some minerals are of strategic importance, and essential to national economic and military security.
- Minerals are different from other forest and rangeland resources because they are more difficult to find, inventory and develop.
- Mineral development is governed by a complex set of laws, and administered by a number of federal agencies.

Minerals are important forest and rangeland resources There are approximately 2,400 minerals, of which 100 are of worldwide economic importance. Minerals are naturally occurring inorganic substances composed of one or more elements. However, for this report, minerals are considered a whole array of geologically derived resources that includes coal and oil used for energy; metallic minerals that contain lead, copper, cobalt, gold, and silver; gems; and the common building materials like sand, gravel, and clay. To simplify the discussion, this report frequently will use the term "mineral" when referring to constituent elements of minerals. Thus iron, when referred to as a mineral, is actually an element found in many minerals such as hematite, bornite, etc.

Differences from Other Forest and Range Resources

A number of factors distinguish minerals from other forest and range resources.

- Unlike other resources found on forest and rangelands, most minerals are nonrenewable, finite, and the result of millions of years of geologic, biologic, and chemical processes.
- Minerals are far more difficult to inventory, explore, and develop than other forest and rangeland resources.
- Minerals are traded in global markets to a greater degree than other forest and rangeland commodities, and governments intervene in the supply and prices of virtually all critical minerals.
- A number of minerals are strategically important to the United States and its allies because of their role in our economy, energy, and the manufacture of weapons systems.
- While the United States has abundant supplies of many minerals, it must depend on foreign countries for some minerals that have critical economic and strategic importance.

Economic Contributions

Minerals are major components of our national, state, and local economies. Nationally, the minerals industry contributed $122.8 billion to the gross national product (GNP) in 1985. Oil and gas extraction accounted for $96.4 billion, coal for $16.9 billion, and metallic minerals and mineral materials for $9.4 billion. Altogether, the minerals industry contributed 3.1% to the total 1985 GNP (U.S. Department of Commerce, Bureau of the Census [USDC BC] 1986). Although the industry's contribution to total GNP may seem small, they supply a large portion of the raw materials on which our economy depends. The U.S. imports far more minerals than it exports, but minerals still are a significant item in foreign trade. In 1985, nonfuel minerals sales overseas totaled $13 billion, about 6% of the dollar value of all exports (U.S. Department of Interior, Bureau of Mines [USDI BM] 1987a; U.S. Department of Commerce, Bureau of Census [USDC BC] 1986). Some 83.3 million short tons of coal worth $2.7 billion were exported in 1986 (U.S. Department of Energy [US DOE] 1987b).

Value added (calculated as receipts plus capital expenditures, minus production and shipping costs) by the mining industry in 1982 totaled $188 billion, accounting for 40% of value added by all raw material industries, which includes agriculture, forestry, and fishing (USDC BC 1984). In 1982, the last year figures from the Bureau of Census are available, 73,000 nationwide establishments employed more than 1.1 million persons in mineral exploration, extraction, and milling, with a payroll of $28.6 billion (USDC BC 1986).

Oil and gas is the largest segment of the industry and employes 600,000 workers, or about 60% of the minerals workforce in 1982. Coal mining follows, with 250,000 workers (23%), mineral materials with 110,000 workers (10%), and metallic minerals industries with 68,000 workers (8%). The minerals industry is made up largely of small companies with less than 20 workers. In 1982, just 14% of the 73,000 minerals establishments counted by the Bureau of the Census had more than 20 employees (USDC BC 1984); however, this 14% accounts for a much larger proportion of minerals production in the United States.

Minerals production and processing are major components of the economies of many states. The importance of minerals to the economies of individual states is indicated by minerals production per capita (table 1). Some states are significant minerals producers. Texas, Louisiana, Oklahoma, California, New Mexico, Wyoming, and West Virginia contributed more than 75% of the $188 billion in value added by minerals production and processing in 1982.

Arizona's copper and Minnesota's iron ores contributed about 33% of the value added by metallic minerals industries. Minerals produced in Colorado, Nevada, New

Table 1. Value of nonfuel and fossil fuel mineral production per capita by state,1985.

State	Population (thousands)	Value of mineral production $ (thousands)	per capita Dollars	per capita Rank	Value of fossil fuel production $ (thousands)	per capita Dollars	per capita Rank
Alabama	4,021	405,915	101	20	1,618,678	403	16
Alaska	521	89,969	173	10	16,322,019	31,328	1
Arizona	3,187	1,550,085	486	3	246,766	77	26
Arkansas	2,359	256,697	109	18	854,107	362	17
California	26,365	2,094,796	79	24	11,866,004	450	15
Connecticut	3,174	72,386	23	47			
Colorado	3,231	408,178	126	16	1,679,821	520	13
Delaware	622	4,029	6	50			
Florida	11,366	1,559,266	137	14	301,681	27	29
Georgia	5,976	946,075	158	11			
Hawaii	1,054	53,272	51	37			
Idaho	1,005	348,154	346	6			
Illinois	11,535	459,920	40	39	2,224,616	193	19
Indiana	5,499	302,954	55	35	964,980	175	21
Iowa	2,884	228,017	79	25	14,893	5	33
Kansas	2,450	322,170	131	15	2,493,154	1,018	11
Kentucky	3,726	267,558	72	27	4,199,363	1,127	10
Louisiana	4,481	522,268	117	17	26,603,982	5,937	3
Maine	1,164	41,108	35	42			
Maryland	4,392	258,274	59	32	75,245	17	31
Massachusetts	5,822	117,205	20	48			
Michigan	9,088	1,347,853	148	12	1,132,335	125	23
Minnesota	4,193	1,547,958	369	5			
Mississippi	2,613	102,793	39	40	1,334,864	511	14
Missouri	5,029	734,960	146	13	5,868	1	35
Montana	828	200,272	242	8	1,681,480	2,036	8
Nebraska	1,606	99,970	62	31	173,110	108	24
Nevada	936	630,883	674	2	73,210	78	25
New Hampshire	998	32,900	33	44			
New Jersey	7,562	177,576	23	46			
New Mexico	1,450	656,889	453	4	4,821,283	3,325	4
New York	17,783	657,308	37	41	132,161	7	32
North Carolina	6,255	432,756	69	28			
North Dakota	685	24,184	35	43	2,040,042	2,978	5
Ohio	10,744	607,127	57	33	1,818,673	169	22
Oklahoma	3,301	251,607	76	26	8,793,517	2,664	6
Oregon	2,687	130,296	48	38	9,800	4	34
Pennsylvania	11,853	804,474	68	29	2,390,547	202	18
Rhode Island	968	12,192	13	49			
South Carolina	3,347	275,929	82	23			
South Dakota	708	207,339	293	7	44,878	63	27
Tennessee	4,762	472,287	99	21	218,195	46	28
Texas	16,370	1,733,359	106	19	36,654,454	2,239	7
Utah	1,645	312,359	190	9	1,597,920	971	12
Vermont	535	49,854	93	22			
Virginia	5,706	381,276	67	30	1,077,737	189	20
Washington	4,409	243,670	55	34	111,838	25	30
West Virginia	1,936	105,409	54	36	3,863,093	1,995	9
Wisconsin	4,775	125,110	26	45			
Wyoming	509	552,463	1,085	1	7,893,991	15,509	2
TOTAL	238,115	22,813,434	$96		145,334,305	610	

Sources: US DOE 1987a–d, USDI BM 1987a.

Mexico, Wyoming, Missouri, and Idaho contributed, (in that order) to another 33% of value added by metallic minerals industries. West Virginia and Kentucky contributed about 40% of the total $18 billion value added by coal mining in 1982, with Pennsylvania, Illinois, Wyoming, Virginia, and Ohio accounting for another 40%.

The domestic minerals industry has been in an economic decline since 1981 when combined production of all minerals peaked. However, the situation varies among sectors of the minerals industry. Bituminous coal production has increased significantly since 1973, while anthracite (hard coal) production has fallen over the past decade. Production of key metallic minerals that include those yielding iron, copper, lead, and zinc has fallen over the past 10 years. This reflects a decline in primary metals manufacturing (USDC BC 1986).

Strategic Importance

Energy minerals and some metallic minerals are of strategic importance to the Nation's security. U.S. military forces could not operate without fuel—a fact recognized by President Taft in 1909, when he set aside oil reserves in California and Wyoming to assure fuel for the Navy (Wilkinson and Anderson 1987). Minerals also are key components of modern weapons systems. Tough, heat–resistant, and lightweight alloys are used in the engines of supersonic jet aircraft; chrome is used to line the barrels of cannon to withstand the force and heat of a high velocity projectile.

Laws That Affect Minerals Resources

The body of law that affects the development of federally–owned minerals is extensive and complex. The most important are the Mining Law of 1872, the Mineral Leasing Act of 1920, the Mineral Materials Act of 1947, the Mineral Leasing Act for Acquired Lands of 1947, the Surface Resources Act of 1955, and the Surface Multiple-Use Mining Act of 1955. These laws determine whether a mineral is "locatable," "leasable," or "mineral materials subject to sale." They control the exploration, development, and removal of minerals owned by the federal government.

General Mining Law of May 10, 1872.—This Act establishes the principles of discovery, the right of possession, assessment work, and patent provisions that cover hardrock minerals on lands reserved from the public domain for national forest purposes The laws applies to lode, placer, and millsite claims and tunnel sites. Except as otherwise provided, all valuable mineral deposits, and the lands where they are found, are free and open to exploration, occupation, and purchase under regulations prescribed by law.

Mineral Resources on Weeks Law Lands Act of March 4, 1917.—This Act authorizes the Secretary of Agriculture (now Secretary of the Interior) to issue permits and leases for prospecting, development, and utilization of hardrock minerals on lands acquired under the authority of the Weeks Law.

Mineral Lands Leasing Act of February 25, 1920.—This Act authorizes the Secretary of the Interior to issue leases for the disposal of certain minerals (currently applies to coal, phosphate, sodium, potassium, oil, oil shale, gilsonite, and gas). The Act applies to national forest lands reserved from the public domain, including lands received in exchange for timber or other public domain lands and lands with minerals reserved under special authority.

Materials Act of July 21, 1947.—This Act provides for the disposal of mineral materials on the public lands through bidding, negotiated contracts, or free use.

Mineral Leasing Act for Acquired Lands of August 7, 1947.—This Act extends the provisions of the mineral leasing laws to federally-owned mineral deposits on acquired National Forest System lands and requires the consent of the Secretary of Agriculture prior to leasing.

Multiple-Use Mining Act of July 23, 1955.—This Act requires the disposal of common varieties of sand, stone, gravel, pumice, pumicite, and cinders under the provisions of the Materials Act of July 31, 1947, and gives the Secretary of Agriculture disposal authority. It also provides that rights under any mining claim located under the mining laws are subject to the right of the United States to management and dispose of surface resources.

Geothermal Steam Act of December 24, 1970.—This Act provides for the leasing of National Forest System lands for geothermal steam development by the Secretary of the Interior, subject to the consent of, and conditions prescribed by, the Secretary of Agriculture.

Mining and Mineral Policy Act of December 31, 1970.—This Act states the continuing policy of the federal government is to foster and encourage private enterprise in the development of economically sound and stable domestic mining and minerals industries and the orderly and economic development of domestic mineral resources.

Federal Coal Leasing Amendments Act of August 4, 1976.—This Act, amending the Mineral Lands Leasing Act, specifies that coal leases on National Forest System lands may be issued only upon consent of, and to conditions prescribed by, the Secretary of Agriculture. It also provides that no leases will be issued unless the lands have been included in a comprehensive land use plan and the sale is compatible with the plan. The Act authorizes the issuance of the license to conduct exploration for coal.

Federal Land Policy and Management Act of October 21, 1976.—This Act defines procedures for the withdrawal of lands from mineral entry. It reserves the rights to prospect for, mine, and remove the minerals in lands conveyed to others to the United States. It also requires the recording of claims with the Bureau of Land Management.

Surface Mining Control and Reclamation Act of August 3, 1977.—This Act provides for cooperation between the Secretary of the Interior and the states in the regulation of surface coal mining. It also restricts or prohibits surface coal mining operations on National Forest System lands, subject to valid existing rights and compatibility determinations.

Energy Security Act of June 30, 1980.—This Act directs the Secretary of Agriculture to process applications for leases and permits to explore, drill, and develop resources on National Forest System lands, notwithstanding the current status of the land and resource management plan.

National Materials and Minerals Policy, Research and Development Act of October 2, 1980.—This Act restates congressional policy to promote an adequate and stable supply of materials with appropriate attentions to a long-term balance between resource production, healthy environment, and natural resource conservation. It also requires the Secretary of the Interior to improve the availability and analysis of mineral data in federal land use decision-making.

The Federal Onshore Oil and Gas Leasing Reform Act of December 22, 1987.—This Act significantly changed the Forest Service's role in leasing and operations. The act gave the Forest Service the authority to analyze and approve any surface-disturbing activity on a federal oil

and gas lease. The Secretary of Interior cannot issue a lease on any National Forest System land over the objection of the Secretary of Agriculture.

Federal Agencies Responsible for Minerals Management

Several federal agencies play major roles in establishing policies and administering programs that affect minerals directly or indirectly. Within the Department of the Interior, responsibility to manage federally-owned minerals, data collection, planning, research, collecting fees, and managing minerals on federal lands is dispersed among five agencies.

The Bureau of Land Management (BLM) manages fossil fuel and metallic minerals for the public domain it administers. BLM also is responsible for minerals retained in federal ownership when surface ownership has been transferred to private parties.

The Geological Survey (USGS) collects information on the Nation's mineral resources. It inventories mineral deposits and their potential.

The Bureau of Mines (BM) collects and analyzes scientific and technical information about the Nation's minerals including supplies, consumption, and the minerals situation worldwide. It also conducts mining research and produces authoritative information on the nation's nonenergy minerals in its annual *Minerals Yearbooks* and other publications.

The Office of Surface Mining, Reclamation and Enforcement (OSMRE) administers the Surface Mining Control and Reclamation Act of 1977 that covers surface mining for coal on both private and public land. Through provisions of the act, OSMRE oversees surface mine regulation by the states and administers a federal fund for reclamation of abandoned mines.

The Minerals Management Service collects revenues from leasing federal minerals both onshore and on the outer continental shelf, and has primary responsibility for development of federal offshore mineral resources.

The Forest Service is responsible for integrating use of minerals with the use of surface resources. To do this, it develops plans for surface and mineral uses, reviews and approves proposals for mineral activities, monitors mineral operator protection of surface resources, and oversees reclamation. The Forest Service is responsible for the management of mineral materials such as rock, sand, and gravel on National Forest System lands.

A number of other agencies, such as the Department of Energy, the Department of Commerce, and the Federal Emergency Management Agency, play roles in the establishment of minerals policy.

States with significant mineral resources also have their own state agencies that oversee minerals management on state-owned and private lands.

Minerals and Indicator Minerals

For the purpose of this analysis of the minerals situation in the United States, minerals have been placed in three broad categories.

1. Energy minerals. These include the fossil fuels coal, oil and gas, and oil shale, as well as other earth resources that provide power such as uranium and geothermal resources.
2. Metallic minerals. These include metallic minerals such as iron, aluminum, chromium, cobalt, molybdenum, copper, lead, gold, and silver. Metallic minerals are essential to many consumer products and industrial processes, and are used in high-technology weapons systems.
3. Industrial minerals. This is a broad category that includes minerals used in industrial processes, construction, agricultural applications, and personal adornment. Industrial minerals include limestone used for metallurgy and cement manufacturing; mineral materials such as sand, gravel, and crushed stone used in road and building construction; phosphate rock used as fertilizer; and gemstones such as diamonds and emeralds.

Major minerals categories and subcategories are shown in table 2.

To simplify the analysis in this assessment of the nation's minerals situation, 13 minerals have been selected as "indicator minerals." These are minerals that have attributes and uses common to other minerals in their class, have common location and market characteristics, and are found in significant amounts in the United States and on national forests. The indicator minerals for each of the three categories are:

1. energy minerals: oil, natural gas, coal, geothermal resources, and uranium;
2. metallic minerals: copper, lead, molybdenum, gold, and silver; and
3. industrial minerals: phosphate rock, limestone, sand, and gravel.

TRENDS IN CONSUMPTION OF MINERALS AND PROJECTED DEMAND

Highlights

- The U.S. is among the world's leaders in important mineral consumption.
- Demand for energy peaked in 1979 and decreased dramatically. However, since 1983 energy use has increased at a moderate rate.
- Demand patterns for metallic minerals vary with the mineral, but there has been a fall-off since 1970. Some consumers have switched to cheaper, non-metal substitutes.
- Demand for energy minerals is expected to increase moderately, with a decrease in the use of oil and an increase in the use of coal.
- Demand for individual metallic minerals is volatile but expected to increase at a modest rate through 2040. High demand growth is expected for scarce and costly specialty metals, such as the platinum-group metals.
- Although the U.S. is a mineral-rich nation, it imports significant quantities of some minerals—especially petroleum.

Table 2.—Categories of mineral resources.

METALS

Metals Used in Iron Alloys

Iron
Chrome
Cobalt
Columbium
Manganese
Molybdenum
Nickel
Tantalum
Tungsten
Vanadium

Base Metals

Antimony
Bismuth
Cadmium
Copper
Lead
Tin
Zinc

Light Metals

Aluminum
Beryllium
Magnesium
Titanium

Precious Metals

Gold
Platinum Group
Silver

Other Metals

Mercury

Minor Metals

Arsenic
Boron
Bromine
Carbon
Cesium
Chlorine
Fluorine
Germanium
Graphite
Indium
Rhenium
Rubidium
Scanium
Selenium
Tellurium
Thallium

ENERGY SOURCES AND GASES

Coal
Natural Gas
Petroleum
Shale Oil
Synthetic Gas
Argon
Carbon Dioxide
Helium
Hydrogen
Neon
Nitrogen
Oxygen
Geothermal

Other

Amber
Fossil Plants, Animals
Peat

RARE EARTH METALS

Cerium
Dysprosium
Erbium
Europium
Gadolinium
Holmium
Lanthanum
Lutetium
Neodymium
Praseodymium
Promethium
Samarium
Terbium
Thulium
Ytterbium

NONMETALLIC INDUSTRIAL MINERALS

Building Material

Gypsum
Limestone
Perlite
Sand & Gravel
Stone, Crushed
Stone, Dimension

Fertilizers

Guano
Limestone
Phosphate
Potash

Insulation

Asbestos
Mica
Vermiculite

Pigments and Fillers

Barite
Bentonite
Clays
Kaolin
Talc

Abrasives

Corundum
Flint
Garnet
Industrial Diamonds
Pumice
Tripoli

Gem Stones

Beryl
Diamond
Emerald
Opal
Sapphire

Ceramic Materials

Calcite
Common Clays
Feldspar
Fluorspar
Glass Sand
Quartz

Decorative Stones

Granite
Marble
Obsidian
Petrified Wood
Slate
Travertine

Minor Industrial Minerals

Greensand
Meerschaum
Staurolite
Wollastonite
Quartz Crystal
Strontium
Zeolites

Diverse Uses

Lithium
Salt
Silicon
Sodium
Sulfur

RARE EARTH MINERALS

Bastnasite
Doverite
Euxenite
Fergusonite
Gadolinite
Monazite
Samarskite
Xenotime

SOURCES: McDivitt and Manners 1974, USDI BM 1979.

- The trend is toward the increase of oil imports, although the U.S. has abundant supplies of coal that could substitute for foreign oil. Some experts say there are significant untapped domestic supplies of oil that could be exploited if prices were favorable.
- For those U.S. metallic minerals in reserve, future trends in imports will depend on the production costs of domestic minerals relative to the price of overseas supplies.

The United States is among the world's leaders in the consumption of many important minerals (tables 3 and 4). With 5.8% of the world's population, Americans consume more than 30% of the world's annual production of natural gas, nearly 26% of the petroleum, 28% of the molybdenum, 27% of silver, and more than 21% of lead and copper. However, other industrialized nations, notably Japan and West Germany, equal or surpass the United States in per capita consumption of some metallic minerals such as copper and iron. There will be increased demand for minerals in world markets as less developed nations industrialize.

National economic activity as reflected by gross national product, in addition to population growth, have some influence over minerals consumption and are expected to increase through 2040 (fig. 1). However, increases in GNP and population do not necessarily mean a proportionate increase in minerals use. Since 1960, energy use per dollar of GNP has steadily declined, probably reflecting the mix of fuels (coal, nuclear, gas, and oil) used to generate electricity, combined with increased efficiency in generating equipment and manufacturing machinery (US DOE 1985). Likewise, per capita consumption of the traditional "tonnage metals" like copper, lead, and iron are declining (Sousa 1987). Changes in the structure of the nation's economy, such as a continuation of growth in the service and communications sectors and decline in energy-intensive manufacturing, could moderate increases in the use of energy and metallic minerals in the manufacture of durable consumer products and industrial machinery. However, significant growth in manufacturing and construction is expected even though those sectors are expected to decline in importance relative to other sectors of the economy (USDA FS 1986a).

Technology also is a factor in minerals consumption through development of new consumer products made with minerals, new processes that permit substitution of renewable materials, processes and products that use energy and minerals more efficiently, and processes that facilitate recovery and recycling. Thus, as technology reduces the amount of metallic minerals and mineral materials required, it also generates new uses and demand for minerals. There is a growing demand for specialty metals used as alloys or in the manufacture of composite materials (Sousa 1987).

Finally, demand also is affected in ways that are unpredictable by changes in social values, such as concerns over toxic materials.

When trends in minerals consumption are examined, the price of minerals in a world minerals market cannot be ignored. World market prices affect the competitive position of the domestic minerals industry by influencing manufacturers' decisions about where they buy the minerals they use. Price also influences consumers' decisions about whether and what to buy and affects overall demand. How prices influence supply is discussed in the Minerals Supplies section below.

Table 3.—U.S. consumption vs. world consumption, 1983.

Commodity	Units	Domestic consumption	World consumption	US % of world total
FUELS				
Petroleum	million barrels/day	15.23	58.76	25.9
Natural gas	billion cubic feet	16,835	54,388	30.9
Coal[1]	trillion Btus	15,900	79,796	19.9
NON-FUELS[2]				
Metals				
Copper	thousand metric tons	2,020	9,520	21.2
Gold	thousand troy oz.	3,060	40,000	7.6
Lead	thousand metric tons	1,141	5,240	21.7
Molybdenum	million pounds	43	152	28.2
Silver	million troy oz.	118.4	428.0	27.6
Materials				
Limestone	thousand short tons	14,902	119,147	12.5
Phosphate	thousand metric tons	34,830	135,000	25.8
Sand, gravel	million short tons	619	8,100	7.6

[1]*Coal figures are given in British Thermal Units (BTUs) because the energy content of a ton of coal varies worldwide. In the United States in 1983, 736.7 million short tons of coal were consumed.*
[2]*Non-fuel mineral consumption is called "demand."*
Sources: USDI BM 1985, US DOE 1987a.

Table 4. Demands for selected minerals and energy, 1955 to 1985, with projections to 2040.

Year	Population	Gross national product	Total energy consumption	Total demand							
				Copper	Lead	Gold	Silver	Molybdenum	Lime	Sand and Gravel	Phosphate Rock
	(millions)	(bill. 87$)	(quad Btu)	(1000 metric tons)		(million troy oz.)		(million lbs.)	(million short tons)		(million metric tons)
1955	165.9	1,767.4	38.82	1,637	1,100	1.3	101.4	38.8	10.5	592	11.1
1965	194.3	2,468.2	52.68	1,982	1,126	5.3	137	68.1	16.8	907	19.5
1975	216	3,174.5	70.55	1,473	1,176	4	153.2	90	19.1	761	31.0
1977	220.2	3,497.9	76.29	2,035	1,435	5.3	123.9	61.4	20.3	926	34.5
1978	222.6	3,774.4	78.09	2,333	1,433	5.1	148.1	67.7	21	992	36.8
1979			78.9	2,433	1,358	5.1	130.6	73.7	21.5	945	39.6
1980	227.8	3,768.1	75.96	2,175	1,070	3.6	91.2	60.6	19.4	762	40.8
1981	230.1	3,841.1	73.99	2,278	1,167	3.5	168.6	61.1	19.3	689	35.1
1982	232.5	3,743.2	70.84	1,761	1,075	3.7	150.1	31	14.4	593	28.8
1983	234.8	3,872.3	70.5	2,014	1,148	3.3	174.8	39	15.1	653	34.8
1984	237	4,128.6	74.06	2,107	1,207	3.4	169.1	41	16.1	772	41.8
1985	239.3	4,224.9	73.96	2,144	1,148	3.4	160	45.4	15.9	798	36.4
1990	249.7	4,780	78.6	2,300	1,300	5.3	140	66	19.2	750	39
2000	268	6,331	87.3	2,800	1,600	6.7	150	71	27.5	1,000	47
2010	283.2	8,052	88.47	3,379	1,820	8.4	162	76	39.5	1,330	56
2020	296.6	10,071	93.15	4,079	2,072	10.7	175	83	56.8	1,771	67
2030	304.8	12,011	97.83	4,923	2,358	13.6	190	90	81.6	2,357	80
2040	308.6	14,214	102.51	5,942	2,683	17.3	206	97	117.4	3,138	95

Index of economic indicators, and demand growth in energy and indicator non-fuel minerals, 1977–2040.

Year	Population	Gross national product	Total energy consumption	Copper	Lead	Gold	Silver	Molybdenum	Lime	Sand and Gravel	Phosphate Rock
1977	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1978	101.1	107.9	102.4	114.6	99.9	96.2	119.5	110.3	103.4	107.1	106.7
1979	0.0	0.0	103.4	119.6	94.6	96.2	105.4	120.0	105.9	102.1	114.8
1980	103.5	107.7	99.6	106.9	74.6	67.9	73.6	98.7	95.6	82.3	118.3
1981	104.5	109.8	97.0	111.9	81.3	66.0	136.1	99.5	95.1	74.4	101.7
1982	105.6	107.0	92.9	86.5	74.9	69.8	121.1	50.5	70.9	64.0	83.5
1983	106.6	110.7	92.4	99.0	80.0	62.3	141.1	63.5	74.4	70.5	100.9
1984	107.6	118.0	97.1	103.5	84.1	64.2	136.5	66.8	79.3	83.4	121.2
1985	108.7	120.8	96.9	105.4	80.0	64.2	129.1	73.9	78.3	86.2	105.5
1990	113.4	136.7	103.0	113.0	90.6	100.0	113.0	107.5	94.6	81.0	113.0
2000	121.7	181.0	114.4	137.6	111.5	126.4	121.1	115.6	135.5	108.0	136.2
2010	128.6	230.2	116.0	166.0	126.8	158.5	130.8	123.8	194.6	143.6	162.3
2020	134.7	287.9	122.1	200.4	144.4	201.9	141.2	135.2	279.8	191.3	194.2
2030	138.4	343.4	128.2	241.9	164.3	256.6	153.3	146.6	402.0	254.5	231.9
2040	140.1	406.4	134.4	292.0	187.0	326.4	166.3	158.0	578.3	338.9	275.4

NOTE. Non-fuel mineral projections are based on the average annual growth rate between 1983 and 2000, as calculated by the Bureau of Mines U.S. Department of the Interior. 1990 and 2000 energy consumption projections are by DOE, 2010–2040 are based on linear regression analysis by Forest Service.

Sources: USDI BM 1981, 1984, 1985, 1987b; US DOE 1987a; USDA FS 1986b

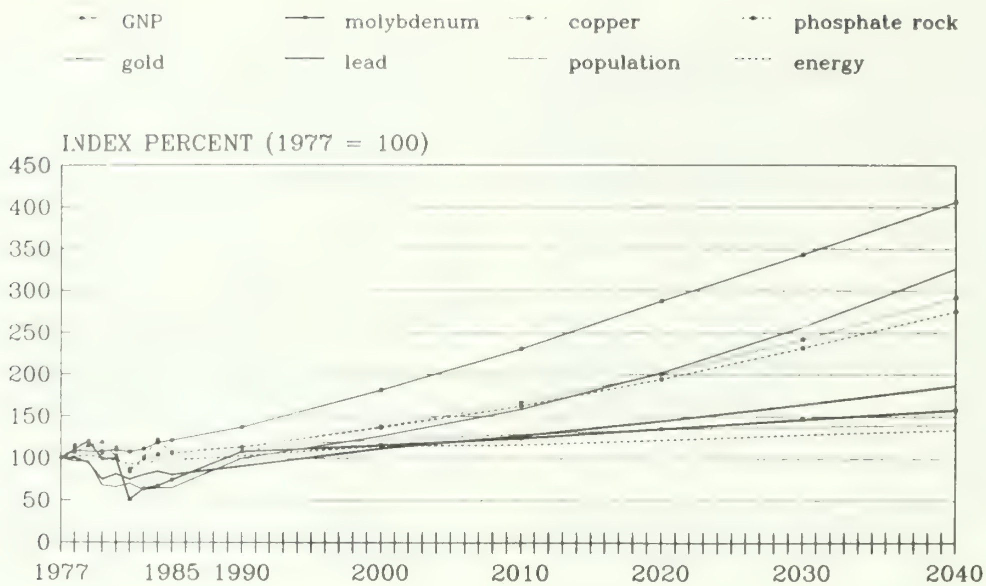

Figure 1.—Index of demand for selected minerals, energy consumption, GNP and population, projections to 2040.

Past and Current Consumption Trends

Energy Minerals

Following World War II, annual domestic consumption of all sources of energy, particularly fossil fuels, increased steadily until 1974, when the Organization of Petroleum Exporting Countries (OPEC) raised oil prices and limited production (table 5). After a significant drop in energy consumption in the mid-1970s, consumption turned upward and peaked in 1979 at under 79 quadrillion British thermal units (quads). There was an abrupt decline in energy use to 70.5 quads in 1983, and since that time consumption has climbed moderately, to 73.9 quads in 1986 (table 6) (US DOE 1987b). Recent demand has been moderated by conservation measures and increased use–efficiency in combination with the decline of energy-intensive heavy industry.

Residential and commercial use accounted for the largest share of energy consumption in 1986—27.25 quads. Industry consumed 25.98 quads, and the transportation sector, 20.69 quads. Electric utilities, energy's middleman, consumed 26.79 quads (US DOE 1987b).

Between 1977 and 1986, each sector's share of total domestic energy consumption changed. The residential-commercial and transportation sectors registered increases (3.6% and 2.0%, respectively), while the industrial sector's share fell a corresponding 5.6%. Electrical utilities consumed 6.5% more energy in 1986 than in 1977 (US DOE 1987b).

Since its inception in 1859, the modern petroleum industry grew at a rapid rate until the late 1970s, spurred in this century by the advent and ever-broadening use of automobiles. At the turn of the century, the United States used 60 million barrels of oil a year; in 1978, Americans consumed almost 7 billion barrels. In less than four generations, U.S. petroleum consumption multiplied more than 100 times, while population only tripled in size (Resources for the Future 1960, US DOE 1987b) Over the past decade, however, the United States has turned increasingly to its abundant coal reserves as a source of energy; between 1977 and 1985, consumption of both petroleum and natural gas declined, while consumption of coal increased 24% (table 6). From 1975 to 1985, the portion of the Nation's energy provided by coal grew from 17.9% in 1975 to 23.6% in 1985. Meanwhile, oil's share of the Nation's energy use fell from 46.4% to 41.8% and that of natural gas from 28.3% to 24.1%.

After sharp growth in the number of nuclear reactors and electricity generated in the early and mid-1970s, nuclear power generation fell late in the decade, hitting a low in 1980. Since 1980, the number of on-line reactors and the amount of power generated have increased (US DOE 1987c). Although nuclear power generation more than doubled between 1975 and 1985, it still provided only 4.15 quads of energy in 1985 (table 6), some 15.5% of all electrical power generated that year. Since 1974, orders for 117 nuclear power plants have been canceled, primarily because of high construction costs, reduced demand, and because it has been cheaper to generate electricity with coal (US DOE 1987c).

Geothermal resources used for electrical generation supply less than three-tenths of 1% of the nation's energy (10.3 million kilowatt hours in 1986), although geothermal power generation has increased about 275 percent from 1977 to 1986 (table 6).

Table 5. Trends in domestic fossil fuel consumption 1949–1985.

Commodity	Unit	1949	1955	1965	1975	1985
Petroleum	mil. barrels per day /quadrillion Btu	5.76/11.88	8.46/17.25	11.51/24.40	16.32/32.73	15.73/30.92
Natural gas	trillion cubic feet /quadrillion Btu	4.97/5.15	8.69/9.00	15.28/15.77	19.54/19.95	17.28/17.85
Coal	million short tons /quadrillion Btu	483.2/11.98	447.0/11.17	472.0/11.58	562.6/12.66	818.0/17.48
TOTAL	quadrillion Btu	29.01	37.42	51.75	65.34	66.25

Source: US DOE 1987a.

Table 6.—Consumption of energy (quadrillion Btu) by source, 1977–1986, with projections to 2000[1]

Source	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1995	2000
Petroleum	37.12	37.97	37.12	34.2	31.93	30.23	30.05	31.05	30.92	31.89	32.2	31.7	31.7	31.8	32.6	34.7
Natural gas	19.93	20.00	20.67	20.39	19.93	18.51	17.36	18.51	17.85	16.53	17.4	17.9	17.8	18.1	18.6	18.5
Coal	13.92	13.77	15.04	15.42	15.91	15.32	15.90	17.07	17.48	17.32	17.8	18.5	18.7	19.1	21.7	23.6
Nuclear	2.7	3.02	2.78	2.74	3.01	3.13	3.20	3.55	4.15	4.48	4.9	5.4	5.7	6.0	6.4	6.7
Hydropower	2.51	3.14	3.14	3.12	3.11	3.56	3.87	3.72	3.36	3.50	([3])					
Other	0.02	0.13	0.07	−0.03	−0.01	−0.02	−0.01	([2])	([2])	([2])	3.8	3.5	3.6	3.6	3.8	3.9
Geothermal	0.08	0.06	0.08	0.11	0.12	0.10	0.13	0.16	0.20	0.22	([3])					
Total	76.29	78.09	78.9	75.96	73.99	70.84	70.50	74.06	73.96	73.93	76.1	77.0	77.5	78.6	83.1	87.

Notes:
[1]*Projection figures are the Department of Energy's "base case forecasts."*
[2]*Less than 0.005 quadrillion Btu.*
[3]*Forecast figures for "other" sources of energy include geothermal and hydropower.*
Sources: US DOE 1987a, 1987b.

Metallic Minerals

Demand patterns in the metals industry vary from metal to metal. In general, consumption of metallic minerals rises and falls in consonance with domestic and worldwide economic prosperity and recessions, and periods of relative peace and military conflict. This is because metals contribute many of the primary materials for consumer products like cars and homes, and military weapons systems. The substitution of industrial minerals like carbon and glass, as well as plastics, in products traditionally made of metal has contributed to a general decline in demand since 1970. However, metallic minerals producers have become more cost-competitive in recent years, and traditional mineral commodities such as iron, lead, and copper are expected to maintain a steady share of the market and realize modest growth (Sousa 1987). Meanwhile, there is the prospect for high demand growth for high value specialty metals, such as the platinum-group minerals, for use in advanced metal alloys and tough, heat-resistant, and lightweight composite materials. One analyst says that ". . . all signs seem to point to a transition of some kind: from a largely undifferentiated commodity metals (and plastics) economy to one in which more highly specialized and technology-intensive materials play an increasingly important role" (Sousa 1987). While the use of precious metals in jewelry and industrial applications generate most of the demand for gold and silver, the psychology of individuals who buy the metals as a financial investment is an important factor. Recent trends in demand for the indicator minerals are shown in table 7 and are discussed below.

Copper.—Over the past 15 years (1972–1987), copper consumption has averaged 2.1 million tons, rising and falling with the economic cycles. Consumption ranged from a low of 1.5 million tons (1975) to a high of 2.4 million tons (1979); in 1987, consumption was 2.2 million tons. The recovery of the mid-1980s following the 1982 recession and inventory build-up (coupled with reduced domestic production) caused a drastic reduction in inventories, and the price for copper (which had been depressed) rose dramatically at the end of 1987. The automobile, housing, and appliance market all expanded and the demand for copper rose. Substitutes have made significant inroads into traditional copper markets and have limited its demand growth. Aluminum, because it is lighter, has challenged copper's dominance in

overhead transmission lines; while drainage pipes, once a major use of copper, now are predominantly made of plastic. Conversely some markets, including automobiles and roofing, have expanded usage (Edelstein 1988).

Lead.—The demand for lead has declined since the late 1970s, but has leveled-off in the 1980s, and is expected to slightly increase into the next century as innovative uses for industrial and commercial traction batteries more than offset its elimination in gasoline. In 1983, lead's use in storage batteries accounted for 73% of total domestic consumption (USDI BM 1985). There has been an increasing demand for lead to shield radiation from television sets and computer video display terminals (Latimer 1987), although the overall health of the industry still depends on demand for starting-lighting-ignition batteries. Recycled lead accounts for about 50% of annual domestic consumption—the highest recycling rate for any metal except antimony (USDI BM 1987b).

Molybdenum.—Molybdenum is used primarily as an alloy agent in steel and cast iron to enhance hardness, strength, and corrosion resistance. Its versatility guarantees a continued demand for the metal, but levels of domestic consumption depend to a great extent on its major market, the steel industry. Since the early 1960s, molybdenum has experienced a domestic annual demand increase of under 1%, but with many peaks and valleys (USDI BM 1985). Demand for molybdenum—both domestically and worldwide—hit its high point in 1979 and sank to an all time low in 1982. Recently, molybdenum has been threatened by a cheaper alloy substitute and trend toward the use of plastics instead of steel (Blossom 1987).

The United States is the major world supplier of molybdenum, exporting more than 50% of domestic production. Because of the desirability of selling the metal overseas to help the Nation's balance of payments, overseas demand must be considered a complement to domestic demand. Although exports have declined for the past decade, the United States exported more than 55 million pounds of molybdenum in 1986 (USDI BM 1987b).

Gold.—Jewelry has always been the most important end use for gold, although industrial uses burgeoned as the electronics industry grew in the 1950s and 1960s. Since 1975, jewelry has accounted for over one-half of all domestic gold consumption, despite high prices in 1980–83. Industrial applications, mostly in electronics, account for 32% of demand. During the last 20 years, dentistry has accounted for 10% to 15%, of demand. Since legalization of private ownership in 1975, consumption of gold in coins, medallions, and other items purchased as investments has amounted to as much as 6% of annual demand. However, investment demand has fluctuated wildly, ranging from a high of 268,000 troy ounces in 1977 to a low of 4,000 troy ounces in 1983, which testifies to the unpredictability of investor psychology.

Silver.—Since 1967, photographic materials have constituted the largest domestic use of silver, followed by the electrical and electronics industry. Almost 7% of use is for jewelry. Domestic consumption peaked in 1973 at 197 million ounces and has since declined, amounting to 118.6 million ounces in 1985 (USDI BM 1985).

Industrial Minerals

Limestone.—Limestone, used primarily as a construction aggregate, is also used for chemical and industrial purposes, steel furnaces, and to reduce particulate emissions from industrial smokestacks, among other uses. Demand and production were steady in the 1970s, but in the early 1980s demand dropped to 75% of the consumption level the decade before.

Phosphate Rock.—The fertilizer industry is the major consumer of phosphate. The domestic fertilizer industry is considered to be mature; little growth is expected given consolidation and some reduction in the agriculture industry. Over the past 10 to 15 years, domestic demand has declined and production facilities have shut down or consolidated. However, two-thirds of annual phosphate rock production is exported, and foreign markets are strong.

Table 7. Trends in domestic non-fuel indicator mineral consumption, 1949–1985.

Commodity	Unit	1949	1955	1965	1975	1985
METALS						
Copper[1]	thousand metric tons	1,056	1,637	1,982	1,473	2,144
Gold[2]	million troy oz.	[3]3.1	1.3	5.3	4.0	3.0
Lead[2]	thousand metric tons	868.8	1,100.1	1,126.3	1,176.7	1,148.3
Molybdenum[2]	million pounds	[3]21.3	38.8	68.1	90.0	33.5
Silver[2]	million troy oz.	97.7	101.4	137.0	153.2	118.6
MATERIALS						
limestone	million short tons	6.3	10.5	16.8	19.1	15.7
phosphate[1]	million metric tons	7.7	11.1	19.5	31.0	36.4
sand and gravel	million short tons	319	592	907	761	799

Notes:
[1]*Apparent consumption*
[2]*Reported consumption*
[3]*Average 1946–1950*
Sources: USDI BM 1977, 1987a, 1987b.

Sand and Gravel.—From the end of World War II until the mid-1960s, the demand for sand and gravel steadily increased at an annual rate of about 8%. Growth slowed and in the early 1980s demand declined to about 590 million short tons. In 1982, demand for sand and gravel reflected the fortunes of the construction industry which, during the 1970s and the early 1980s was battered by inflation, high interest rates, effects of the OPEC oil embargo, and general economic recession. Since 1982, consumption has grown to more than 800 million tons. The United States exports a small amount of sand and gravel (USDI BM 1985, 1987b).

Projected Trends in U.S. Demand

Energy Minerals

The *Annual Energy Outlook* published by the Department of Energy's Energy Information Administration projects energy demand only to the year 2000. Its base case consumption forecasts for selected years through 2000 by energy source are shown in table 8.

In order to project energy demand to 2040, as required for this assessment, an energy supply demand model developed by Jae Edmunds and John Reilly (1986), Institute for Energy Analysis, Oak Ridge Associated Universities, was used. The model, developed for the Department of Energy, projects long-term production of atmospheric carbon dioxide from consumption of worldwide energy. The model projects consumption of energy from oil, gas, solids (encompassing coal and biomass), and nuclear energy at decade intervals through the year 2050. Since the model's benchmark year differed from this assessment, a trend line was developed and used to establish projected demand levels for the assessment's benchmark years. The projected demand for the four categories of energy, in Btu and units by which each commodity is traditionally measured, is shown in table 9.

The price of energy, discussed in detail in the section on minerals supplies, will have a major influence on demand and the sources Americans tap for their energy. Rising oil prices could stimulate a shift to use of domestic coal and biomass-based fuels, including wood. Moreover, increased prices for oil could make production of synthetic fuels (gas from coal and gasoline substitutes from corn and other vegetable substances) and the use of alternative energy sources, such as solar and wind, economically viable.

Some authorities believe the nation is in a period of transition from reliance on fossil fuels—especially petroleum and natural gas—to substantial use of renewable energy sometime in the next century. Under this scenario, rising prices and uncertain supplies of petroleum will lead to increased use of coal and a concentrated effort to develop renewable energy technologies (Backus 1981).

Metallic Minerals

To project long-term demand for any specific metallic mineral is difficult because domestic demand is influenced by many factors, some that relate to economic and social developments in the United States, others to world economic, political, and military events that influence levels of supply and consumer prices.

As with energy minerals, demand for metallic minerals has been linked to population growth, gross national product, and disposable incomes. The vigor of the domestic durable goods manufacturing sector, communications, and defense industries have a bearing on the domestic demand for metallic minerals. The demand for gold and silver is largely influenced by the world price of these precious metals.

The Bureau of Mines has projected consumption of some important minerals to the year 2000, based on analysis of trends in GNP, gross private domestic investment, Federal Reserve Board production indices, and

Table 8.—Summary of projected base case energy consumption.

	1987	1988	1989	1990	1995	2000	Annual rate of change 1987–2000 (percent)
	quadrillion Btu						
Petroleum	32.6	33.0	33.4	33.7	35.1	36.3	0.8
Natural Gas	17.4	17.4	17.8	17.8	18.9	20.2	1.2
Coal	18.0	18.0	18.3	18.8	20.8	22.6	1.8
Nuclear	4.9	5.3	5.5	5.9	6.3	6.4	2.1
Hydropower/Other[1]	3.3	3.5	3.7	3.8	3.9	4.1	1.6
Total	76.2	77.2	78.7	80.0	85.0	89.6	1.3

[1]*Includes industrial generation of hydroelectricpower, net electricity imports, and electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems.*
Source: US DOE 1987a.

Table 9. Projections for energy demand through 2040.

Commodity	Units	1987	1991	1995	2000	2005	2040
Coal	Quadrillion Btu	22.99	25.96	29.19	33.22	29.93	37.67
	Billion short tons	1.04	1.18	1.33	1.51	1.36	1.71
Oil	Quadrillion Btu	27.56	28.63	29.69	31.01	31.94	36.28
	Billion barrels	4.75	4.93	5.11	5.34	5.50	6.25
Gas	Quadrillion Btu	16.83	15.74	14.65	13.29	15.25	25.81
	Trillion cubic feet	16.29	15.23	14.18	12.86	14.76	24.98
Nuclear	Quadrillion Btu	4.67	5.55	6.43	7.53	8.47	14.51
	Billion kilowatt-hours	432.04	513.46	594.87	696.64	783.60	1342.39

Note. The figures in quads were derived from the Edmunds model. To calculate demand in units by which each commodity is traditionally measured, Department of Energy's thermal conversion rates were used. For coal, the average heat content of all coal in 1986 was 21.932 million Btu short ton. Edmunds' projections are for biomass solids, a major part of which are coal. We subtracted 10% of the projected biomass demand to calculate coal demand after the year 2000. For oil, the thermal conversion factor used was 5.800 million Btu/barrel. For gas, the heat content calculated was 1,033 Btu/cubic foot. For nuclear power plant generation, DOE used the weighted annual average heat rate for nuclear steam-electric plants in the U.S., which was 10,809 Btu/kilowatt-hour in 1986.

Sources: Edmunds and Reilly 1986, US DOE 1987b.

population growth. For purpose of this assessment, the Bureau of Mines' projections of average annual probable demand through 2000 for the indicator minerals (table 10, fig. 1) were extended to 2040. These projections provide a picture of what future demand might be *if present trends continue*. For example, the Bureau of Mines projects the demand for copper to grow at an average annual rate of 1.9% through 2000. By projecting this to 2040, the domestic demand for copper would increase from the 2.1 million metric tons consumed in 1985 to 5.9 million metric tons. Similarly, at a 2.4% average annual growth rate, domestic consumption of gold would increase from 3.0 million troy ounces in 1985 to 17.3 million troy ounces in 2040. However, it is impossible to anticipate technologies that may have a profound influence on consumption of individual minerals. Some of the factors expected to affect future demand are discussed below. Except where otherwise noted, the discussion is drawn from *Minerals Facts and Problems, 1985 edition* (USDI BM 1985).

Copper.—Because of its use in construction, manufacturing, and communications, copper's fortunes depend to a large degree on the health of the Nation's economy. Modest growth that amounts to 1.9% annually is projected through 2000. Copper will face increased competition from substitutes in some markets, but new uses in electronics and communications, and the recapture of some older markets in construction and transportation, are projected to more than offset losses. Nearly 60% of the forecast for probable total end-use demand for copper in the year 2000 is in electrical products. Growth in this sector, copper's most important market, closely matches projections of gross private domestic investment. Copper's use by the electrical and electronics industry is not expected to decline further before 2000, and use by the construction sector is expected to increase somewhat as copper roofing and other uses are revived. A significant portion of domestic demand for copper has been met by the recovery of old scrap, which has averaged 35% of total domestic demand for more than half a century. This proportion is not expected to grow much before 2000. Scrap recovery diminishes during periods of low prices, and the international availability of inexpensive primary copper discourages recycling.

Lead.—Trends in demand for lead are linked strongly to growth of the auto industry; 75% of lead production is used in automobile batteries. Past demand for lead has matched growth in GNP, and projections for a moderate but steady growth in demand averaging 1.3% annually through the year 2000 is linked to projected growth in GNP. Increased use of lead by the electronics industry and recapture of the lead cable sheathing market should contribute to a rising demand for lead.

Molybdenum.—Some 75% of molybdenum production is used as a steel alloy, and the fortunes of the steel industry, both domestically and in other countries, will largely determine demand for molybdenum. Prevailing demand patterns plus some growth in demand for specialty steels containing molybdenum alloy are expected to continue through the end of the century. This will contribute to a modest but stable overall demand growth of under 1% a year through 2000. Since the majority of domestic production of molybdenum is exported (62% in 1986), overseas industrial development will play a significant role in global demand for molybdenum (USDI BM 1987b).

Gold.—The demand for gold is projected to grow at an average annual rate of 2.4% until 2000. Gold demand is influenced strongly by the world price of the metal. Demand for gold in the form of jewelry and luxury items—more than one-half of gold's market—responds to the metal's world price, rather than changes in GNP or population. Demand for gold in dentistry, expected to comprise about 10% of gold's market in the year 2000,

Table 10. U.S. total demand projections in the year 2000.

Commodity	Units	Low	High	Probable	Average annual growth rate 1983–2000 (percent)
METALS					
Copper	1,000 mton	2,400	3,500	2,800	1.9
Gold	1,000 oz.	5,000	8,300	6,700	2.4
Lead	1,000 mton	1,100	2,200	1,600	1.3
Molybdenum	mil. lb.	60	100	71	0.8
Silver	mil. oz.	120	180	150	0.8
MATERIALS					
Limestone	1,000 ston	21,900	35,200	27,500	3.7
Phosphate	1,000 mton	45,000	50,000	47,000	1.8
Sand and gravel	mil. ston	650	1,230	1,000	2.9

Source: USDI BM 1985.

will be influenced by the development of substitutes, improved oral hygiene, and the possible advent of government programs that would expand access to dental care. Projected growth in the electronics component industry—gold's other major market—depends on trends in equipment longevity, substitution, and discovery of new industrial applications. Increased demand for gold investment products is expected to be minimal.

Silver.—Only moderate growth in the demand for silver—eight-tenths of 1% as an annual average—is anticipated over the next decade as industries that use silver in manufacturing consume less silver per product unit and as substitutes increase their market share. Improved recovery methods for used silver are expected to further dampen the demand for newly-mined metal. The trend toward substitutes and increased use-efficiency is expected to affect foreign markets as well as domestic, although larger demand growth is projected for the rest of the world, not for the United States.

Industrial Minerals

Limes.—The chemical and industrial sector is the biggest user of lime, the commodity produced from limestone. In 1983, the chemical and industrial sector used 10 times the amount of lime as the construction industry, limestone's second biggest market. By 2000, the amount of limestone used for chemical and industrial purposes is projected to nearly double 1983 consumption levels—to 24.6 thousand short tons or nearly 90% of domestic consumption. These estimates are based on a projected 1.8% growth in the iron and steel industry, and an expected increase in demand for lime in the environmental sector—for use in cleaning smoke stacks, sewage treatment, and land reclamation. Demand for lime in agriculture is expected to remain even. The projected 3.7% annual average growth in the demand for limestone is based almost exclusively on expected growth in the chemical and industrial sectors.

Phosphate Rock.—Projections for increased demand for phosphate rock in the year 2000 are based primarily on the expectation that there will be growth in both the export and domestic markets. The Bureau of Mines projects probable average annual growth in these two markets through the year 2000 at 1.8%. The U.S. share of world phosphate sales is expected to decline because the U.S. phosphate industry will slowly lose its ability to supply its markets as reserves are depleted. There will be a significant increase in supply from North African and Middle Eastern countries that will replace lost production in the United States and help supply the forecasted increase in demand.

Sand and Gravel.—Current trends and end-use shares are expected to continue. Between 1974 and 1983, 45% of all sand and gravel was used for concrete aggregates and concrete products. Increased use of crushed stone as a substitute for sand and gravel in concrete, asphalt, and road-base uses is expected to significantly affect demand for sand and gravel. An important factor in substitution decisions are safety regulations and environmental restrictions. Delivery costs increase the end-user prices and encourage the search for substitutes like crushed stone.

Trends in Minerals Imports

Although the United States is a mineral-rich nation, it imports significant quantities of some minerals. Oil is imported to supplement domestic supplies. Some minerals are imported even though there are active mines in the United States because it is cheaper to buy overseas than to develop and produce domestic supplies. Other metallic minerals are imported because the minerals do not occur in the United States in sufficient quantities or domestic resources are uneconomic given current prices and technology.

However, the United States also exports significant amounts of some minerals. The United States is the world's major supplier of molybdenum, exporting 59 million pounds of the 94 million pounds produced in 1986 (USDI BM 1987b). Less than 1% of domestic production of limestone rock (2.8 million tons of the 770 million tons produced) was exported in 1986. The United States also exports significant amounts of some minerals that it also imports in large quantity. For example, in 1986, the United States imported 16.7 million tons of iron ore, produced 38.8 million tons, and exported 4.5 million tons. In 1986, the United States exported $24 billion worth of nonfuel minerals. The United States also is a major international supplier of coal, marketing $3.9 billion overseas in 1986 (US DOE 1987a). Though it imports more than half of the petroleum consumed domestically, the United States sold petroleum products worth $3.5 billion overseas in 1986.

Energy Minerals

The Nation's oil imports rose steadily from 1960 to 1977 when imports accounted for nearly one in every two barrels of oil (46%) consumed in the United States (about 8.6 million barrels a day). U.S. reliance on foreign oil fell to 27.3% of consumption (4.3 mbd) in 1985, then increased to 32.8% (5.3 mbd) in 1986 (table 11). The National Energy Plan projects foreign oil to account for 16% of U.S. consumption (8.3 mbd) in 2010. Other observers expect far heavier U.S. reliance on foreign oil, perhaps exceeding 50% of domestic consumption by 1991 if present trends in U.S. consumption and production persist (Abelson 1987, US DOE 1987e). However, the United States has abundant supplies of coal, oil shale, and natural gas that could replace imported oil in some cases, depending on technology and the economics of production. There is some evidence that significant supplies of onshore oil remain that could be exploited with new technology (Fisher 1987).

Metallic Minerals

Imports of metallic minerals have fluctuated considerably over the past decade. The percentage of indicator minerals imported is shown in table 12. The United States has consistently imported substantial amounts of copper, lead, gold, and silver. The United States is the world's largest supplier of molybdenum.

For those U.S. metallic minerals in ample supplies, future trends in imports of these minerals will depend in large measure on the cost of domestic minerals relative to the cost of overseas supplies, and on world political and economic factors. Moreover, the strength or

Table 11.—Net fossil fuel imports as a percent of consumption, 1960–1986.

Commodity	1960	1965	1970	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Crude oil	16.5	19.8	21.5	35.8	46.5	42.5	43.1	37.3	33.6	28.1	28.3	30.0	27.3	32.8
Natural Gas	1.2	2.8	3.6	4.5	4.9	4.6	5.9	4.7	4.4	4.9	5.1	4.4	2.5	4.4

Source: US DOE 1987b.

Table 12.—Total net import reliance of indicator non-fuel minerals as a percent of consumption, 1977–1986.

Commodity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
METALS										
Copper	13	20	13	16	6	1	19	23	28	27
Gold	61	53	53	18	15	42	30	37	46	21
Lead	13	9	5	NE	1	11	20	20	13	20
Molybdenum	NE	NE	NE	NE	NE	NE	7*	NE	NE	NE
Silver	31	48	42	7	53	55	59	58	59	71
MATERIALS										
Limestone	2	3	3	2	2	2	2	1	1	1
Phosphate Rock	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Sand and Gravel	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

"Unusually large decreases in domestic stocks resulted in a positive net import reliance as a percent of consumption." (U.S. Department of the Interior, Bureau of Mines 1987b, p. 106)
NOTE.—"NE" denotes net exporter.
Source: USDI BM 1981, 1984, 1987b.

weakness of the domestic economy relative to other developed nations could lead to policies and programs intended to bolster domestic production and manufacturing. Such a scenario could promote the development and exploitation of domestic mineral reserves. The continued low value of the dollar in relation to the currency of other countries also could make domestic minerals more cost-competitive with foreign minerals and decrease the use of imported minerals. Threats to foreign supplies through armed conflict or political instability in critical source countries, and U.S. policy aimed at maintaining minerals independence could also reduce imports.

Industrial Minerals

The United States does not import significant amounts of industrial minerals materials and is a net exporter of phosphate rock and sand and gravel.

THE NATION'S MINERALS RESOURCES

Highlights

- The Nation is rich in many of the minerals it requires, but there is uncertainty about the extent of the minerals resources.
- While minerals are distributed widely around the Nation, coal is concentrated in the Allegheny Plateau, the Ohio River Valley, and the Great Plains; oil is found mostly in the southwest and south; and many metallic minerals occur predominantly in the upper Lake States and the mountains and valleys of the West.
- Ownership of the Nation's minerals is complex and there is little information on quantities of minerals in public and private ownership.
- The quantity of recoverable oil is uncertain over the long-term, but the Nation has abundant coal reserves, oil shale and tar sands, uranium, and the potential for greater use of geothermal resources.
- The U.S. possesses large quantities of many metallic minerals, although they may not be economical to develop at current prices or with available technology.
- There are large quantities nationwide of minerals materials used in construction, though urban development threatens their availability in some areas.

Because minerals are contained in soil and rock, some at great depths, the extent of the Nation's minerals resources will never be known. While minerals are nonrenewable and thus finite, the reserves generally are expandable through investment in exploration and development, and the development of new techniques for minerals discovery and recovery.

Little is known about the total extent of the Nation's minerals resources (Cameron 1986). Nonetheless, the United States is rich in many of the minerals it requires. In 1986, it was among the top three producing nations worldwide of more than 30 of the 87 minerals monitored by the Bureau of Mines and a major producer of several others (table 13). For many mineral commodities, even for some of those that are imported, the United States has significant known reserves. For example, the domestic reserve base of copper, which the United States imports in significant quantities, is sufficient to last more than 40 years at 1985 consumption rates (table 14). However, there are no economic domestic supplies of some metallic minerals of economic and military importance.

Table 13. Minerals of which the United States is among the top three world producers.

Aluminum	mercury
barite	mica
beryllium	molybdenum
boron	ammonia
bromine	perlite
cadmium	phosphate
cement	quartz crystal
copper	rare earth metals
diatomite	rhenium
feldspar	salt
industrial garnet	silicon
germanium	sodium carbonate
gypsum	sulfur
helium	talc and prophyllite
lime	titanium
magnesium	vermiculite

Source: USDI BM 1987b.

There is disagreement over quantities of recoverable onshore oil in the contiguous United States. However, the United States has abundant supplies of coal, oil shale and tar sands, uranium for nuclear power, and potential for development of additional geothermal resources.

The amount of oil in recoverable domestic reserves, as estimated by the Department of Energy, would last 9 years at mid-1980s production rates. This recoverable reserve base estimate in terms of years of supply is about the same for natural gas. Domestic coal reserves are considerably more extensive—these reserves would last over 500 years at current production rates.

Location

Generally, the areas of highest mineralization are the mountains and basins of the West and the Appalachian chain in the East (fig. 2). However, minerals of economic importance are widely scattered throughout the United States. For example, there are identified iron deposits in all but six states. Moreover, ores predominantly of one mineral often contain another mineral that can be produced economically as a byproduct or co-product. For example, cadmium often is a byproduct of zinc and cobalt is a byproduct of copper and nickel. Coal underlies about 13% of the Nation and occurs in 37 states (U.S. Department of Agriculture, Forest Service [USDA FS] 1979), although the bulk of the Nation's coal reserves

Table 14.—Domestic and world supply, demand and reserve base for non-fuel minerals, 1985.

Mineral	Units	US Mine Production	US Consumption[1]	Reserve Base[2]	Years to Exhaust Reserves[3]	World Mine Production	World Reserve Base	Domestic % of World Reserve Base
METALS								
Copper	1000 mton	1,106	1,906	90,000	47	8,114	556,000	16
Gold	mil. oz.	2.48	2.99	120	40	48.22	1,490	8
Lead	1000 mton	424	1,113	26,000	23	3,390	142,000	18
Molybdenum	1000 lb.	108,409	33,451	11,800,000	353	215,139	26,000,000	45
Silver	mil. oz.	39.4	119	1,800	15	412.3	10,800	7
MINERAL MATERIALS								
Limestone	1000 ston	15,713	15,865	adequate		125,531	adequate	
Phosphate	1000 mton	50,835	36,384	5,200,000	143	151,863	36,000,000	14
Sand and Gravel	1000 ston	829,530	798,800	([4])		not. avail.	([4])	

[1]*Usually both reported and apparent consumption figures are given for each commodity. Reported consumption, usually the lesser figure, was chosen for this table since apparent consumption usually includes recycled material.*

[2]*The "reserve base" constitutes that part of identified resourced which may reasonably become economic to exploit, without assuming current technological or economic standards.*

[3]*The number of years it will take to exhaust the reserve base at 1985 consumption rates as indicated above.*

[4]*"The reserve base is controlled largely by land use and/or environmental constraints. Local shortages of sand or gravel are common" (p. 137, USDI BM 1987b)*

Source: USDI BM 1987b.

are located beneath the Allegheny Plateau and Cumberland Plateau in the East, the Ohio and Mississippi River Valleys, and the Great Plains (fig. 3). Major oil and gas basins are concentrated in an area that extends from Oklahoma south to southern Texas, the Appalachian basin, with scattered deposits beneath the eastern plateaus and in western basins (fig. 4). Geothermal resources occur mainly in the West (Honig, et al. 1981).

Although deposits of a given mineral commodity may be found in many areas of the nation, production typically is far more limited (USDI BM 1987b, Honig et al. 1981.) For example, although there are deposits of copper throughout the Appalachian Mountains, Missouri, Oklahoma, Michigan, Minnesota, and all the western contiguous states, only six states (Arizona, Michigan, Montana, Nevada, New Mexico, and Utah) produce significant amounts of copper, and the bulk of U.S. production comes from Arizona and Utah (National Research Council 1979).

Ownership

There is little information on the quantities of minerals in public and private ownership. This is, in part, because little is known about what minerals actually exist. Further, no agency maintains statistics on the ownership of known deposits, although BLM has records for federal lands. At best, the ownership of minerals is extremely complex and often transitory; for example, minerals located on federal land become private property with the discovery of a valuable mineral deposit and the filing of necessary legal papers. The key question is not one of who owns the minerals but whether they are accessible and available for development and under what conditions.

While significant amounts of minerals are believed to lie beneath federal lands, these lands account for a relatively small proportion of domestic minerals production, which indicates that large amounts of minerals are in private ownership. For example, most of the phosphate produced in Florida comes from private lands and nearly all the iron ore produced domestically is mined on private land in Minnesota's Mesabi iron range.

There is some information on the federal government's ownership of energy minerals. In the West, the government owns about 60% of the 237 billion tons of identified coal reserves (USDI Office of Surface Mining, Reclamation and Enforcement 1987).

When the federal government acquired the national forests in the East, it often did not buy the subsurface minerals, and while some minerals rights have subsequently been purchased by the federal government, the rights to minerals beneath large areas of the eastern national forests remain in private ownership. In the late 1970s, it was estimated that private owners hold the rights to minerals under one-third of the 25 million acres of national forests in the East (Shands and Healy 1977).

Energy Minerals

According to the Department of Energy, in 1985, the United States had proven reserves (quantities deemed recoverable from known reservoirs under existing economic and operating conditions) of crude oil of 28.4 billion barrels, which amounts to about a 9 year supply at mid-1980s production rates. DOE estimates that there are about 82.6 billion barrels of undiscovered recoverable crude oil (US DOE 1987b). The United States has substantial amounts of natural gas. A 1988 study for the Department of Energy estimated that technically

Figure II-2
Map of Mineralization
Locations of Favorable to Metallic Ore Deposits

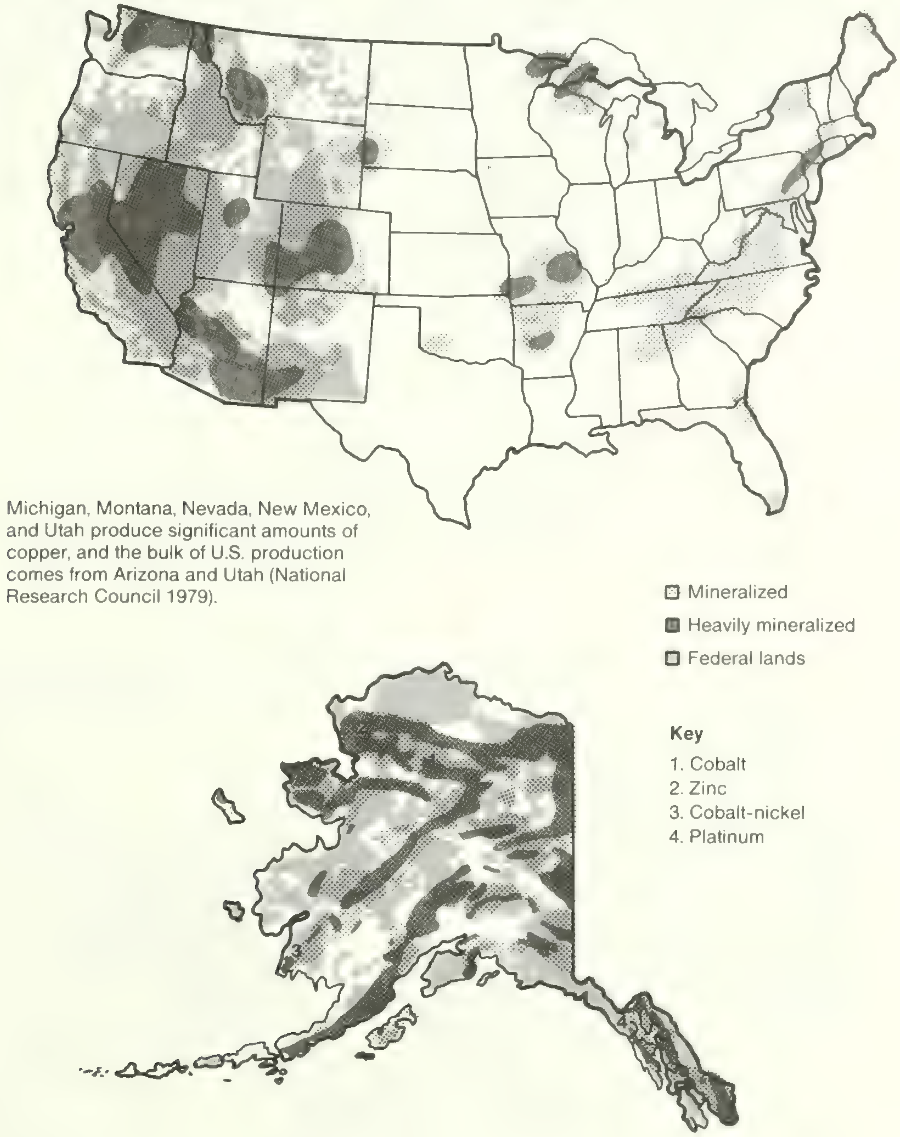

Figure 2.—Locations of favorable mettallic ore deposits.

recoverable natural gas in the U.S. reserve and resource base amounted to 1,188 trillion cubic feet (Argonne National Laboratory 1988). This figure includes 1,059 trillion cubic feet beneath the 48 contiguous states, and another 129 trillion cubic feet in Alaska. To put these amounts in perspective, as of 1984, the United States had produced a cumulative total of 130 billion barrels of crude oil and 650 trillion cubic feet of natural gas (US DOE 1985).

However, other experts contend that there are 300 billion barrels of oil that could be recovered, although it will require expensive new technology (Abelson 1987).

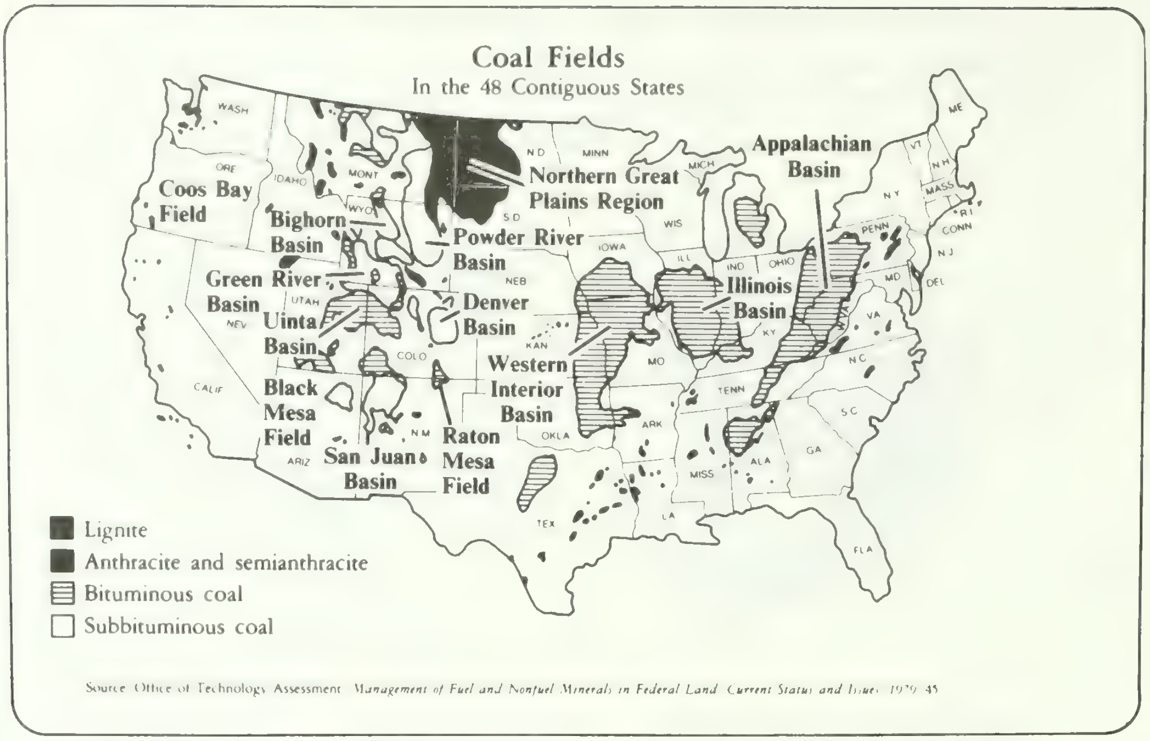

Figure 3.—Map of coal areas (U.S. Congress, Office of Technology Assessment, 1979).

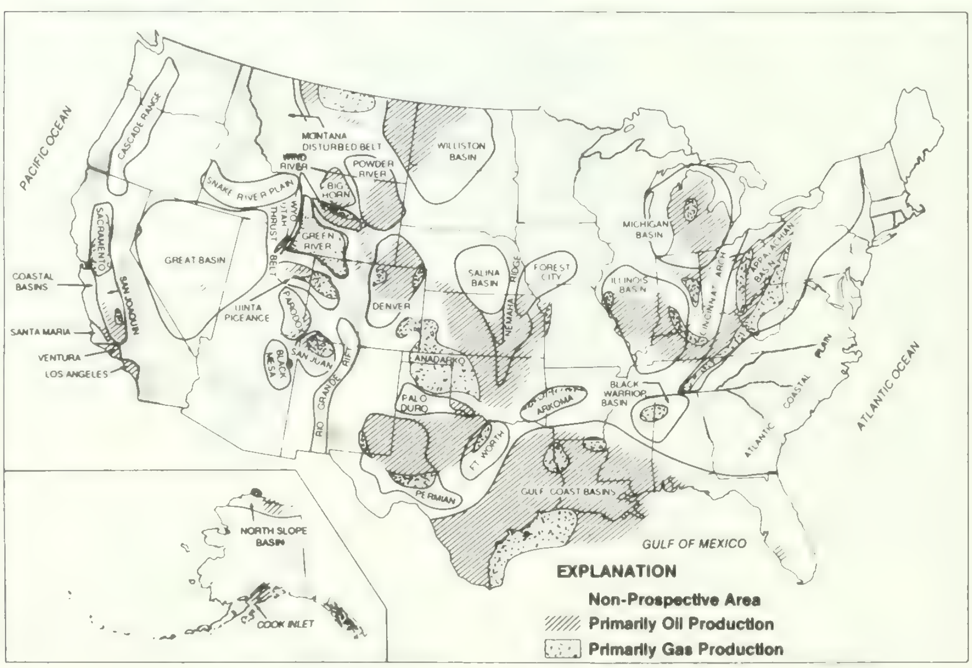

Figure 4.—Major oil and gas basins.

The potential for development of these resources is discussed in the following section on supply.

The United States has abundant supplies of coal. The nation's reserves of coal are estimated at 478.2 billion short tons (in 1985, the United States consumed 818 million short tons). There also are large reserves of oil shale with estimates ranging from the equivalent of several hundred billion barrels of oil, to more than a trillion barrels (Abelson 1987). The Nation also has large amounts of uranium, if required for nuclear power generation. There also is the potential for increased use of geothermal resources; the Department of Energy believes that

RESOURCES OF (commodity name)
(A part of reserves or any resource category may be restricted from extraction by laws or regulations (see text))
AREA: (mine, district, field, State, etc.) UNITS: (tons, barrels, ounces, etc.)

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Measured	Probability Range	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Margianl Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Figure 5.—Resources/reserves classification system.

by 1995, geothermal energy sources could provide more than double the electrical power they now generate.

Metallic Minerals

The United States has large quantities of many metallic minerals, although not all can be recovered economically at current prices or with available technology. The U.S. Geological Survey and Bureau of Mines have a system for describing the Nation's minerals resources (fig. 5) based on geologic knowledge and the economics of minerals extraction. The two major classifications are "resources" and "reserves." Resources encompass all the Nation's minerals, discovered and undiscovered. Reserves comprise minerals that have been discovered and may be either economic or marginally economic to recover, given current technology. The resource is economic if the costs of extraction and production allow the miner to profit financially from the operation.

The Bureau of Mines defines the "reserve base" as that part of the resource that might be mined given current mining and production processes. The reserve base includes all economic and marginal reserves, and a portion of the uneconomic reserves (Dorr 1987, USDI BM 1987a). The reserve base is dynamic and constantly changes because of new discoveries, new technology, and flux in local, national, and global economies. Table 14 displays the 1985 domestic reserve base estimates for the indicator minerals. The implications of these reserve base estimates for future supply are discussed in detail in the following section.

Industrial Minerals

The Nation has adequate reserves of limestone and phosphate rock (table 14), but lacks reserves of some important industrial minerals such as industrial diamonds. Mineral materials used in construction, such as sand, gravel, stone, and clay, are abundant nationwide, and widely distributed. Because of their weight and bulk, transportation is costly and typically, these materials are extracted and processed close to where they are used. While deposits typically exist near metropolitan areas, they may be rendered inaccessible by urban development, zoning regulations, and environmental restrictions (USDI BM 1985).

THE MINERALS SUPPLY SITUATION

Highlights

- While world production of oil currently is in excess of demand, increased consumption by OPEC nations and political factors could reduce the amount of foreign oil available for purchase by the U.S.
- There are abundant supplies of metallic minerals worldwide, but their cost and security of supply raise questions about their availability.
- The market for many minerals is global and complex, and for some minerals there are frequent periods of shortages or oversupply.
- A number of minerals critical to the U.S. economy or military are controlled by unstable or unfriendly governments and vulnerable to regional conflict.

- Supplies of some minerals can extend through more efficient use, conservation and recycling.

Minerals are traded in world markets to a far greater degree than other forest and rangeland resources. Domestic reserves are only one possible source of the minerals required to satisfy the Nation's needs. Thus, an assessment of minerals supplies must consider the world minerals situation. For most minerals the United States requires, there appears to be adequate worldwide supplies to anyone with the money to buy them. The question is where the United States will get the minerals to satisfy its needs and at what price.

World prices for a mineral affect the economics of exploiting domestic reserves. International politics and economics weigh heavy in industry's decisions about minerals exploration, mine development, and production. For minerals of strategic or economic importance that the United States imports in significant amounts, the critical issue is security of supplies that arises from political and economic instability of the source countries and military conflict. However, supplies can extend through more efficient use of minerals by industry, conservation by consumers, and recycling. Increased domestic production from all sources may be required during periods of military conflict.

How Prices Affect Minerals Supplies

The price of a mineral commodity is a critical variable in the supply calculus. If supplies are inadequate relative to demand, prices increase and stimulate exploration and development of mineral resources. On the other hand, a rise in prices tends to cause a decrease in consumption, either through a switch to available less expensive substitutes, conservation, or deterred use in new product or process. The words of the U.S. Department of Energy that ". . . prices play a key role in balancing domestic energy consumption, production, and [foreign] trade" (US DOE 1985) are also true for metallic minerals.

In a perfectly operating market, at some price, supply and demand reaches equilibrium—supply matches demand and some stability is achieved. In the case of some minerals, particularly abundant domestic mineral materials, the market system works well and supply and demand appear to be near equilibrium. For other minerals, the market does not work well and there are frequent periods of shortages and oversupply.

The reasons for this include the price inelasticity of most minerals and the global nature of a complex market. The decisions of individual countries or a group of nations that control a large portion of the world's supply of a mineral can reverberate worldwide. The short-term effect of decisions by OPEC on worldwide supply and prices of oil is well known. Organizations of major producing countries exist for other minerals as well. Even a single nation can have a significant effect on supplies and prices. Chile is the world's leading copper producer and its state-owned National del Cobre de Chile accounts for nearly 14% of production (Hargreaves and Fromson 1983). Thus, Chile can exert a major influence on the world copper market.

Some economically depressed countries are willing to sell their minerals at relatively low prices for foreign exchange (USDI BM 1985). This depresses world prices and discourages domestic exploration, development, and production.

The value of the dollar to other currencies also affects domestic production. A high-value dollar effectively reduces the price of foreign minerals, making them more competitive with domestic sources (USDI BM 1985).

Prices also affect the development of new technology to recover hard-to-exploit reserves, convert coal to liquid fuel, recycle, or develop substitute materials.

Energy Minerals

Supplies of oil exist in a number of free world nations in addition to the United States. The nations of the Organization of Petroleum Exporting Countries (OPEC) dominate the supply. Three-fourths of known world reserves are in OPEC countries, and two-thirds of the reserves are in five nations bordering the Persian Gulf (US DOE 1987a). The United States possesses only 4% of the known world oil reserves (Hargreaves and Fromson 1983). While there appears to be significant supplies of petroleum worldwide, the long-term picture is uncertain. Even though OPEC nations have a surplus supply, this could change. OPEC's share of world oil production is expected to rise significantly through the rest of this century; however, consumption of oil by OPEC members is expected to triple by the year 2000 and limit the amount available for export (US DOE 1987a).

Domestic supplies of oil are uncertain over the long term. It appears that most of the easily recoverable supplies of petroleum are depleted; fields in the contiguous states have been pumped for many years, causing a decline in recovery rates. The average output of domestic wells in 1984 was 14 barrels a day, compared to 801 in Mexico, 4,100 in Norway, 5,341 in the United Kingdom, and 12,011 in Saudi Arabia (Abelson 1987).

There is evidence that significant reserves of petroleum exist, but are expensive to recover and require new technology (Fisher 1987). If the price of crude oil increases, investment in these resources can become attractive. In fact, the United States continually adds technology to make oil economically recoverable, enlarges the areas of proven reserves, and makes new discoveries. The 9-year reserves-to-production ratio has held level (or increased) for more than three decades (US DOE 1987a).

Concern over potential environmental impacts has generated opposition to development of petroleum reserves on public lands, on the outer continental shelf, and in Alaska.

The outlook for supplies of natural gas is bright. According to a 1988 report prepared by the Argonne National Laboratory for DOE, of the 1,059 trillion cubic feet of natural gas recoverable in the lower 48 states, more than one-half—583 trillion cubic feet—is judged

to be economically recoverable at a wellhead cost of less than $3 (1987 dollars) per million cubic feet, including finding costs. If this is the case, the United States has, at current levels of consumption, a 35-year supply of natural gas at a cost equal to or below $3 per-million cubic feet (Argonne National Laboratory 1988). An additional 174 trillion cubic feet is economically recoverable at prices between $3 and $5 per million cubic feet.

The United States has enough coal reserves to last several hundred years. It also has significant amounts of natural gas and reserves of other fossil fuels (oil shale and tar sands) that are costly to develop but can substitute for oil. The domestic supply of uranium is sufficient to supply any foreseeable demand, with potential for increased development of geothermal resources.

Metallic Minerals

There are abundant metallic minerals resources worldwide. Considering only indicator minerals, the world reserve base is sufficient to satisfy demand at 1985 production rates for many years (table 14). The same is true of all important minerals. Although worldwide supplies of critical metallic minerals are adequate, the cost of foreign minerals and the supply security of minerals of economic and strategic importance raise questions about future availability of some minerals that the United States depends on. For example, 60% of the internationally traded copper is controlled by the nations of the Council of Copper Exporting Countries (Chile, Peru, Zambia, Zaire, Australia, Indonesia, Papua-New Guinea, and Yugoslavia). Nearly three–fourths of the world's chromite reserves are in South Africa (Hargreaves and Fromson 1982).

As previously noted, the reserve base of a mineral is constantly changing because of new discoveries, changes in the world prices, and new technology that reduces cost of exploration and extraction. Because of this flexibility in the amount of material the reserve base encompasses, long-term supply forecasts are uncertain. Supply projections are limited by their dependency on current reserve base estimates. With the exception of gold and silver, the United States has more than 16% of the world's reserve base or adequate reserves of the five metallic indicator minerals. Even in the case of gold and silver, the domestic reserve base is not insignificant. Nonetheless, the United States supplements domestic production of four of the indicator minerals (copper, lead, gold, and silver) with foreign imports. By dividing the reserve base quantities by 1986 consumption levels and assuming no new discoveries are made, it appears that the U.S. reserve base for copper, lead, gold, and silver will be exhausted in less than 50 years. Cameron (1986) compared production to reserve base for a number of minerals and concluded that ". . . the U.S. mineral position is weak with respect to a number of important minerals" and unless production (and consumption) fall or new reserves are discovered, the Nation's minerals position "will become significantly weaker through 2005."

However, reserve base estimates should be evaluated with caution, particularly when calculating long-term supply trends. Cameron's data do not mean that the Nation will run out of minerals, only that increased exploration and development is needed to maintain equilibrium between production (consumption) and supply. Supply generally increases with a rise in demand, illustrated in the case of gold. With a strong demand for gold in the mid-1980s, about 80% of all funds invested in minerals exploration in the United States focused on that precious metal (USDI BLM n.d.). More than 40 new mines opened nationally in 1986. Moreover, changes in world prices or more efficient mining and processing technologies could make current uneconomic reserves profitable to develop or stimulate exploration for new reserves. For example, by using new processing techniques, today's industry can extract copper from low-grade ores that were once uneconomical to mine.

In some cases, even deposits that are likely to remain uneconomic should count as part of the Nation's long-term supply. For example, the Bureau of Mines reports progress in recovering manganese (a vital steel alloy element the United States imports from South Africa) from several plentiful, but low-grade, domestic deposits. Although uneconomical to produce, these deposits could serve as an emergency source (Federal Emergency Management Agency 1987).

Moreover, abundant supplies of many minerals are known to exist on the seabed, but cannot be recovered economically (U.S. Department of Commerce, National Oceanic and Atmospheric Administration 1987). Because of the strategic importance of some of these minerals (especially manganese and cobalt), the Bureau of Mines is conducting research on deposits on the ocean beds controlled by the United States, as well as recovery technologies (Federal Emergency Management Agency 1987). It is possible that these offshore deposits could be economical to recover during the 50-year period covered by this assessment.

Industrial Minerals

Because of their weight and bulk, mineral materials used for construction are typically mined near where they are to be used. Thus, domestic not foreign supplies are the critical factor. Nationally, the United States has sufficient supplies of mineral materials, although there are local areas where mineral materials used in construction, such as sand and gravel and rock aggregate, do not occur or only occur in limited amounts. When local supplies are exhausted, the materials must be delivered from a distance—which is an increase in cost to the consumer. Sand and gravel is hauled by unit train from Montana to North Dakota where the material is in short supply (LaMoure 1988). In those areas where supplies of mineral materials exist, land use and environmental constraints are major factors that affect supply (USDI BM 1985).

For limestone, supply and demand is essentially in equilibrium. However, domestic consumption slightly exceeds the domestic production of the mid-1970s.

Table 15.—Recycling of non-fuel minerals as a percent of consumption, 1986.

Commodity	Units	Amount recycled	Apparent consumption	Percent
METALS				
Aluminum	1000 mton	784	5,143	15
Copper	1000 mton	479	2,136	22
Gold	mil. oz.	1.4	3.3	42
Lead	1000 mton	566	1,134	50
Molydenum	Recycled as a component of steel scrap independent of molybdenum content.			
Silver	mil. oz.	23	200	12
Tin	1000 mton	10,975	51,535	21
MATERIALS				
Limestone	"Large quantities" are regenerated by industry.			
Phosphate Rock		NONE		
Sand and Gravel	Road and concrete surfaces on a limited, though increasing basis.			

NOTE.—The meaning of the term "recycling" changes depending on commodity. Here, recycling refers to the quantity of material recovered from discarded products and old scrap not generated by current operations. This definition limits the contents of the recycling bin to material that must be substantially converted and refined through what usually are called "secondary production" processes.
Source: USDI BM 1987b, 1988.

The United States has abundant supplies of phosphate rock and produces a surplus for export.

Recycling: Another Source of Supply

The United States currently recycles a relatively small proportion of the minerals it consumes; most is lost in the waste stream (table 15). However, in the case of a few minerals, recycled material is an important domestic source. For example, there is no real domestic source of tin, yet in 1986, about 20% of the 51.5 million metric tons consumed came from recycled material (USDI, BM 1987b). Some 50% of domestic lead came from recycled material, primarily auto batteries. Recycling is affected by many of the same factors that influence development and processing of an in-ground mineral deposit, the price of reclamation relative to purchase of new supplies, degree of concentration of a mineral in waste, and available recycling technology.

The Nation's Strategic Stockpiles

The United States has stockpiles of petroleum and some critical metallic minerals to assure their availability in case of an interruption of foreign supplies. However, this is costly and contributes to the budget deficit. Moreover, when supplies are available only from foreign sources (or in the case of oil, require increased overseas purchases) acquisition contributes to the foreign trade imbalance. Thus, stockpiles are built at variable rates.

The Nation has a Strategic Petroleum Reserve goal of 750 million barrels of oil. As of December 1986, the reserve's oil inventory was 511.6 million barrels. An average of 51,430 barrels a day were added to the reserve during 1986 (US DOE 1987f). The Omnibus Budget Reconciliation Act of 1986 requires that the reserve be filled at the rate of 75,000 barrels a day. The 1987 Act did not require a specific fill rate. Instead, the fill rate is based on the 1988 budget. The Strategic Petroleum Reserve was appropriated $438.7 million dollars, of which $256.4 million is used to fill the reserve. The average daily fill rate of 50,000 barrels is based on the latter amount. The National Defense Stockpile of nonenergy minerals and some other strategic materials has excess inventory over goals in some minerals, but these are outnumbered by inventory deficits.

Security of Foreign Supplies

A number of minerals critical to the U.S. economy or military are controlled by unstable or unfriendly governments and are vulnerable to disruption by regional conflict. The assurance of supply, United States vulnerability to long- or short-term disruptions, and the timely ability to locate and develop alternative or onshore sources are of equal concern to this Nation. As discussed earlier, two-thirds of the free world's known oil reserves are held by Mid-East OPEC nations that border the Persian Gulf. In 1987 and 1988, oil tankers and port facilities were the targets in the war between Iran and Iraq. Several countries are constructing pipelines to the Red Sea and Mediterranean ports to provide oil shipping outlets less vulnerable to attack (US DOE 1987b). Nonetheless, Mid-East oil supplies remain uncertain in a region where oil is seen as a military and political weapon and a small number of countries control the bulk of the free world's supply.

Table 16. Minerals high in strategic risk*, major producing nation(s).

Mineral	Risk	Producing nation(s)	U.S. import reliance (1986)
Chromium	41.5	South Africa, Zimbabwe	75
Manganese	36.7	South Africa, Australia	100
Cobalt	35.3	Zaire, Zambia	94
Copper	28.8	Chile, Peru, Philippines, Zaire, Zambia	28
Platinum Group	28.8	South Africa, Canada	92
Gold	26.4	South Africa	46
Aluminum	23.0	Canada, Guyana, Indonesia	26
Alumina and Bauxite	NA	Australia, Guinea, Jamaica	97
Columbium	22.3	Brazil, Canada, Thailand, Nigeria	100
Tin	21.8	Brazil, Malaysia, Bolivia, Indonesia, China, Thailand, Chile	74
Diamond industrial	19.0	Botswana, Namibia, South Africa, Zaire	92

** Strategic risk index figure is based on a calculation of the likelihood of a supply disruption and its potential economic cost. An index figure over 25 is considered highrisk, 10 to 25, medium risk.*
Sources: Hargreaves and Fromson 1986; USDI BM 1987a.

A similar situation exists for some critical metallic minerals, precious metals, and minerals materials used in industrial processes. Hargreaves and Fromson (1986) developed a complex system to evaluate the vulnerability of supplies of 38 minerals of strategic importance to industrialized nations. Factors evaluated include stability of the governments of producing nations, probability of armed conflict, and vulnerability of transportation routes. Table 16 shows the minerals that ranked highest in strategic risk, the major producing countries, and 1986 United States import reliance. As the chart indicates, of the minerals ranked highest in strategic risk, in 1986 the United States imported more than three-quarters of domestic consumption of seven of them. Two of this assessment's indicator metals, copper and gold, are rated high in strategic risk. However, gold is not a strategic mineral and adequate quantities of refined material are held domestically, as are reserve assets. The others, lead, molybdenum, and silver, are either relatively abundant or available from secure sources of supply.

HOW SUPPLY COMPARES TO EXPECTED DEMANDS

Highlights

- Domestic consumption of minerals of all kinds will increase.
- The U.S. has sufficient supplies of many of the minerals it requires, although it will continue to rely on foreign sources for some minerals of economic and strategic importance.
- Where the U.S. gets the energy and metallic minerals it consumes depends to a large degree on the cost of domestic exploration and recovery versus overseas prices.
- While the demand for metallic minerals will increase moderately overall, new technologies will stimulate the demand for some minerals and reduce consumption of others.

Demand forecasts indicate that compared to today's levels of consumption, the United States will require increased supplies of minerals through the year 2040. There are ample worldwide supplies of all the minerals the United States requires. For some minerals of economic or strategic importance, the United States will rely on foreign sources and stockpiles. Most minerals, even those the United States imports in significant quantities, are or could be produced domestically in amounts sufficient to satisfy domestic demand if the cost of domestic exploration and production competes with overseas sources and the regulatory climate is favorable.

This section summarizes the information from the previous sections that describe the projected domestic demand for minerals and the U.S. and world supply situation, with a description of the likely future.

Minerals Demand: Summary and Analysis

Energy Minerals

The United States demand for energy minerals will increase. The kinds of mineral resources used to satisfy domestic demand and where they are obtained will depend on the cost of domestic minerals relative to those from foreign sources. Price also will be affected by technological advancements in minerals exploration and recovery.

The world price of oil is expected to increase during the 1990s and into the next century. This should stimulate exploration and development of domestic oil sources, utilization of oil shale and tar sands, and increased use of domestic coal and natural gas. However, the demand for coal, oil shale, and tar sands will be influenced by the development of technologies that reduce costs and environmental effects. Public concern

over acid precipitation and other environmental problems linked to coal burning could stimulate governmental action that increases the cost of coal-generated electricity to the consumer. Such concerns depress the demand for coal and stimulate the use of oil and gas, if available at reasonable prices. Geothermal resources will be developed where economically feasible. Despite past low costs, future growth of nuclear power generation and the demand for uranium will depend on measures to reduce health and safety risks. This includes the provision for disposal of high-level nuclear waste and public attitudes toward nuclear power Moreover, new technology that makes renewable, nonmineral energy cost-competitive with mineral sources could reduce the demand for energy minerals.

Metallic Minerals

In general, the domestic demand for metallic minerals will continue to increase. The Bureau of Mines forecasts growth rates averaging about 20% for selected indicator minerals through 2000. However, new technologies and products will stimulate the demand for some metallic minerals and reduce the demand for others. The forcefulness of the market is illustrated by lead; while its use as a gasoline additive is being phased out, it is now in demand to screen radiation from televisions and computer monitors (Latimer 1987). Over the 50-year planning period, demand for any given metallic mineral is likely to be highly variable.

Industrial Minerals

Demands for mineral materials used in industrial processes and construction are likely to follow trends in population growth and gross national product. Demand for fertilizer minerals could be affected by new farming techniques and overall demand for agricultural commodities that the United States produces.

The Minerals Supply Situation: Summary and Analysis

Energy Minerals

Overall, there will be no shortage of any energy minerals worldwide, although the price of oil is expected to increase significantly. The United States has ample supplies of mineral resources that could serve as alternatives to oil—natural gas, oil shale, tar sands, and uranium for nuclear power. Likewise, there are opportunities for increased use of geothermal resources to generate electricity.

Metallic Minerals

The United States has supplies of many metallic minerals sufficient to accommodate domestic demand through the assessment period. However, the United States does not have supplies of some metallic minerals of economic and strategic importance and will have to continue to depend on foreign sources. For those minerals that are present in the United States, the cost of foreign supplies vis-a-vis the cost of domestic production largely will determine the extent to which domestic demand is satisfied by domestic supplies. Restrictions on exploration, minerals production from federal land, and environmental concerns could limit domestic supplies of some minerals. For some minerals that the United States imports in significant quantities, the availability of overseas supplies will be influenced by factors unrelated to the physical existence of the resource, such as global and regional politics and the stability of the government of the producing country.

Industrial Minerals

The domestic supply of mineral materials used in construction historically has been in equilibrium with demand and no national shortage is anticipated. However, local deposits of mineral materials used in construction can deplete, and result in rising costs to consumers for transport of needed materials from distant areas.

Price/Cost and Supply Interactions

As discussed previously, the price of a mineral—or its cost in world markets—influences supply as well as demand. Higher prices stimulate domestic exploration, development, and production of a mineral—increasing supplies, but with increased costs to consumers. Similarly, rising prices serve as an incentive to increase utilization of existing reserves, more efficient use of raw materials in manufacturing, a switch to less expensive substitutes, and consumer conservation.

Other economic factors not directly related to minerals also will influence minerals consumption and demand. These include efforts to reduce the federal deficit (seen in reduction of additions to U.S. strategic stockpiles), need of foreign countries for cash, value of the dollar relative to foreign currencies, and U.S. balance of trade. Interest rates, federal and state tax policies, the price of labor, and the cost of environmental protection affect the competitive position of the domestic minerals industry. They also affect the amounts of domestic minerals consumed and demands upon domestic resources.

The Future

The ways the nation's minerals needs are satisfied—either through increasing or extending supplies—shift as the national and world economic situation changes and new technology is brought on line. This will continue. In terms of increasing the quantity of available domestic minerals, trends seem to indicate the following:

• There will be a continued reliance on foreign sources to supplement domestic supplies for both energy and metallic minerals when the price of overseas minerals is less than the cost of producing them domestically.

• Rising prices for worldwide fossil fuel energy minerals will stimulate exploration for and production of domestic energy sources. There will be an increased reliance on domestic reserves of coal.

• Domestic production of metallic minerals will rise as new exploration and recovery technologies make domestic minerals cost-competitive with foreign sources.

• There will be an increase of growing demand for industrial minerals, especially materials used in construction.

The following section considers the social, economic, and environmental implications of these trends, emphasizing increased domestic production.

SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF THE SUPPLY/DEMAND COMPARISONS

Highlights

- There is likely to be increased domestic minerals production to satisfy demand, although the U.S. will continue to import significant amounts of minerals it requires.
- The national economy will benefit from increased domestic minerals production through reduced imports and the mining industry's increased contribution to the Nation's gross national product.
- Greater domestic production will have positive and negative regional and local economic and social impacts. Positive effects will include increased jobs and higher incomes. Negative effects include the need for government investment in facilities and services; some shortages (probably short-term), in services and housing; and changes in the social and political structure, and culture of small rural communities.
- Potential environmental impacts include changes in lands and soils; esthetic degradation: and adverse impacts to water quality, and fish and wildlife habitat.

The comparison of demand and supply in the previous section indicates there is likely to be increased domestic production to satisfy demand. The United States will continue to import some minerals, either because they cost less overseas or because no economically exploitable domestic deposits have been discovered. Increased domestic minerals production will contribute to the health of the national economy; but the economic, social, and environmental effects will be most evident in communities where the mineral activity occurs or is restricted. Greater reliance on imported minerals also would have important national economic impacts and affect regions and localities.

National Effects

Encouragement of domestic minerals production would benefit the national economy in at least two ways. First, the nation's balance of trade with foreign countries will improve as U.S. industries use more domestic minerals. Imports will decline if domestic prices are favorable. If there is a production surplus, exports might increase as well. This will have a beneficial effect on the Nation's general economy and a lower reliance on potentially unstable foreign sources.

Second, the economic climate for domestic minerals industries will improve, and increase their contribution to the gross national product.

Increased minerals imports will aggravate the Nation's already serious international balance of payments deficit. The situation will be especially acute in the case of oil. While the Nation enjoyed relatively inexpensive foreign petroleum in the mid and late 1980s, experts generally agree that low foreign oil prices are not likely to last beyond 1990, and prices will rise significantly in the next century (US DOE 1985). If present import trends continue, the national bill for foreign oil could amount to $200 billion by the year 2000, about one-half of the total foreign debt in 1987 (Abelson 1987). This would place a heavy burden on the national economy.

The net import of minerals on the health of the U.S. economy, however, depends in part on the price of imports. As long as the price of foreign minerals remains low and other sectors of the economy are vigorous, the national economic effects of increased minerals imports might not be significant. Although the domestic metallic minerals industry's share of the GNP declined between 1981 and 1985, overall GNP rose (USDC BC 1986). Increased imports of relatively cheap foreign oil actually helped keep inflation in check.

Dependence on imports could have serious consequences during a time of rapid price increases. If the domestic minerals industry is unable to rapidly initiate or expand production because of United States reliance on foreign sources, the national economy could be stressed by disruptions in foreign supplies or price increases. This is similar to what happened in the case of OPEC oil in the early and mid-1970s.

The social and environmental effects of increased domestic minerals production will be widely dispersed and probably not be apparent at the national level.

Effects on Regions and Communities

Increased domestic production can be expected to have positive and negative regional and local social and economic impacts. Those impacts will be focused primarily in the areas where minerals activity occurs.

Increased onshore oil and gas production is most likely to affect parts of Alaska, the northern Rocky Mountains, and the Southwest. Increased domestic coal production will primarily affect localities in the Appalachians and coal regions of the upper Great Plains. The increase of domestic metallic minerals production

will impact primarily the West and the iron ore producing areas of the upper Great Lakes. Although larger mineral operations have greater potential for social, economic, and environmental effects, there are few large metallic minerals mines. Of 296 metallic mineral mines in the United States in 1985, only 121 produced more than 100,000 tons (USDI BM 1987a). The increase in demand for industrial minerals, especially those used in construction, will result in greater numbers of quarries throughout the country. These also tend to be relatively small operations. The vast majority of the more than 6,000 sand and gravel quarries in the United States in 1985 produced less than 100,000 tons of material a year.

Economic Impacts

Increased domestic production will have positive and negative effects in regions and localities where minerals development takes place. Positive effects include an increase in direct employment in minerals activity and higher personal incomes. The increase in employment also leads to expansion of secondary jobs and income in the retail sales and service sectors. State and local tax revenues will increase because of the increases in the direct and secondary employment. There also are likely to be short-term negative economic impacts. State and local investment will be required to pay for additional facilities such as roads, water supply, and sewers, and public services such as police and fire protection, schools, hospitals, and recreation. Short-term shortages in facilities and services can be corrected over time. Recent legislation in states such as Montana and Wyoming require minerals developers to finance some of the new social infrastructure through prepayment of taxes (Montana code annotated 75–20–101 to 1205, Wyoming Statute 35–12–101–121). Established residents may face an increase in housing costs and other goods because of an increase in demand by new residents. Other sectors of the local economy, such as agriculture, also may face higher costs for resources such as water and labor because of the demand increase stimulated by mining activity. Ultimately, there will be some financial stress when depletion or market changes lead to closure of the minerals development.

A number of factors affect the balance of adverse and beneficial economic effects: size of the mine and value of the mineral mined; number of workers employed and skills required; development pace; and duration of activity (Wenner 1984). The policies of the developing company to hire local people and buy in the local economy can affect the economy of the community. Large mining companies make deliberate efforts to maximize the local economy and establish cooperative relationships that address local concerns (ASARCO 1982).

The characteristics of a local community that affect its ability to accommodate economic growth are size, degree of isolation; government's and business sector's ability to cope with growth; opportunities for advanced planning, labor supply; and whether the economy is diversified, single-sector, stable, or depressed.

In some cases, increased national reliance on foreign sources of minerals will cause domestic mines to close, which results in losses of jobs and depression of regional or local economies where minerals production is a major element. For other communities, the loss of a domestic minerals market to overseas sources means a loss in economic growth and diversification through development of local minerals resources.

Whether the decline of a local mine or its closure results in a net loss to the community depends largely on the availability of other economic opportunities in that community. Other sectors of the economy may expand and compensate for lost minerals activity. Some port cities will realize economic benefits from increased minerals imports. Consumers also can benefit from imports if those imports prices are lower than domestic sources.

In summary, the national economy can expect to improve as a result of increased production of domestic sources. Regional and local economies will benefit from employment and income increases, but may feel pressure to provide facilities and services for greater numbers of workers and their families. Increased imports, on the other hand, will contribute to problems at the national level. This includes increases in the Nation's international trade deficit, although consumers may benefit from cheaper imported goods. Increased imports can cause negative impacts on local communities if domestic mines close because they are not cost-competitive with foreign supplies.

Social Impacts

As in the case of economic impacts, the development of domestic mineral resources can be expected to generate positive and negative social effects. Increased economic activity and employment can generate feelings of social well-being. New jobs also will make it possible for young people to remain in the locality. New employment opportunities may attract an influx of workers and their families and change the social and political structure, and culture of small rural communities (USDA FS 1980). This influx may lead to friction between newcomers and established residents, especially if they differ in culture, education, and economic status. An increasing population requires more schools, increased health care systems, law enforcement, and social services. A larger population will stimulate long-term improvement in social services, medical facilities, schools, and cultural and entertainment opportunities.

Some communities are more capable than others to assimilate new people and meet housing and social services demands. A community's ability to cope with social disruption depends on many of the same factors that affect its ability to deal with economic change. Generally, communities that suffer employment and income losses also will have difficulty adjusting to the social demands of large-scale minerals development.

The regional and local effects of increased imports of foreign minerals at the expense of domestic production

also will be mixed. If foreign imports result in the closure of domestic mines, many individuals will lose their jobs. These individuals would have to move to other areas, take less desirable jobs in the same locality, or possibly accept short-term public welfare.

In summary, the social effects of increased domestic production are felt mainly at the regional and local levels. Social benefits relate to long-term job increases, higher incomes, and improved social services and cultural and educational opportunities. However, there are likely to be short–term adverse effects because of cost increases to local governments, social changes that accompany rapid, and unplanned growth, and changes in the character of local communities.

Environmental Impacts

Increased domestic minerals production has potential for adverse environmental impacts in the areas where minerals development occurs.

The increased use of foreign minerals results in less environmental concern in this country. The direct environmental effects of the minerals development is transferred overseas to developing countries where environmental standards are far less stringent than in the United States.

The nature and severity of potential environmental impacts depend on a number of factors. Among them are the ecological character of the land developed; the mineral mined; methods to extract and concentrate the ore; the use of available technology to mitigate adverse impacts; policies of the mining company; and the enforcement of mitigating measures by local, state, and federal entities. Many laws and regulations address the environmental impacts of mining. Enforcement at all levels could effectively mitigate many of the significant effects experienced in the past.

Some environmental effects are site specific, such as storage of mine tailings. Others have broader regional effects, such as water pollution.

Environmental effects also vary in duration. Some effects are greatest when the mine is active. Changes in the landscape and toxicity of mine waste can persist long after mine operations cease. Often post-mining impacts, particularly water pollution, are the most difficult to mitigate (National Research Council [NRC] 1979, U.S. Environmental Protection Agency [US EPA] 1985).

The U.S. Environmental Protection Agency (1987) studied 31 "environmental problems" that included mining waste. Mining waste was rated in four categories of environmental risks and found low in non-career health risks and welfare effects, moderate in cancer risk, and high in ecological risk.

While some short-term environmental degradation may be inevitable, there are measures that can be taken to avoid or mitigate most of the adverse environmental effects (PEER Consultants 1984, US EPA 1985). Enforcement of federal, state, and local environmental quality laws will prevent some of the most serious adverse environmental effects. For example, the Surface Mine Control and Reclamation Act (SMCRA) provides for federal incentives to states to regulate surface coal mine operations and ensure adequate reclamation. Congress exempted mining from coverage under the Resources Conservation and Recovery Act (RCRA) pending a study by the U.S. Environmental Protection Agency of the hazards of mining waste (US EPA 1985). Subsequently, EPA has studied the concern and found that mining wastes do not require management as do hazardous wastes under Subtitle C of RCRA. A regulatory program (Subtitle D of RCRA) is under development. Some localities have zoning laws and regulations that minimize conflict between minerals development and other land uses. There is evidence that the mining industry has responded to public pressure and federal legislation of the 1970s with improved techniques that reduce environmental effects, such as the reclamation of mined lands (Cameron 1986).

Increased domestic minerals production will have various environmental effects on land use, soils, esthetics, water quality and quantity, wildlife, and potentially human health in localized areas. The most significant effects are summarized below.

Increased domestic minerals development will lead to land disturbance that will temporarily remove some areas from timber production, range forage, wildlife habitat, and recreation uses. However, the amount of land in the nation actively used for mining is relatively small. In 1980, the last year figures were available, 228,000 acres of land were actually used for mining nationwide (Johnson and Paone 1982). From 1930 through 1980, only one-fourth of 1% of the U.S. land was utilized for mineral extraction. A 1984 study on coal surface mining estimated 73,000 acres were "newly disturbed" nationwide, and the total disturbed area amounted to 146,000 acres (PEER Consultants 1984). The commitment of land is not large when compared to the Nation's total surface, even in areas where mining activity is or has been prevalent. For example, Kentucky, Pennsylvania, and West Virginia only have about 2% of their total land area disturbed; Illinois, Indiana, and Ohio have had about 1% (Johnson and Paone 1982). Phosphate mining in central Florida affected 166,000 acres, or only 3.2% of the land in a seven-county area, compared to 9% for urban development (NRC 1979).

Mine sites can be reclaimed for beneficial uses, such as open space, fishing lakes, and wildlife habitat. In the mountainous areas of the East, level sites can be used for playfields and housing (NRC 1984, Stearns 1985). The ease and effectiveness of reclamation depends on topography, the nature of the soil, waste material, and rainfall (National Academy of Sciences 1974, US EPA 1985). In contrast to the past, there are expected to be fewer waste dumps and tailings that resist revegetation and are left unsuitable for human use or wildlife habitat.

Minerals development can affect the long-term land and soil condition. Soil compaction changes soil physiology. Soil chemistry can be altered by the introduction of toxics, both of which yield soil conditions that make revegetation difficult. It was estimated that 1.3 billion metric tons of waste would be generated

by mining extraction and processing in 1985 (US EPA 1985). Of this, 361 million tons would be toxic or acidic to some degree, making reclamation difficult and costly.

Increased underground mining increases the potential for subsidence, while disposal of waste on steep slopes increases the potential for erosion and slumping (PEER Consultants 1984). Increased phosphate mining in some areas will result in greater amounts of mine slimes (waste clays deposited as a slurry) that take decades to stabilize (NRC 1979).

Mineral development, especially waste piles that have not been reclaimed, adversely affect scenic quality. For example, coal mining in Appalachia and metallic minerals development in the West adversely affect scenic quality near the mine site. Coal mine highwalls are seen from highways in the mountains of Kentucky, West Virginia, and Virginia. Copper mine waste piles are seen from the highway through scenic mountains east of Phoenix, Arizona. The visual impact is greatest from surface mining. Surface mining accounts for 95% of metallic minerals and minerals materials extracted in the United States and 99% of mine waste (NRC 1979).

Increased minerals development increases the chance of surface and underground water pollution. This pollution is in the form of drainage, seepage, and runoff from the mine site, waste dumps, and tailings. Depending on the mineral and method of concentrating, the ore runoff may contain toxics. The disposal and treatment of water laden with chemicals is a technological challenge. There also is a risk of accidental discharge of waste through failure of retention dams and pipes (NRC 1979). A recent study found that "only a small percentage of [metallic minerals] mines currently monitor groundwater, use run-on/runoff controls or liners, or employ leachate collection, detection, and removal systems" (US EPA 1985).

Water quality also can be a problem after mine operations cease. Subsurface contamination is a difficult problem with abandoned deep mines (NRC 1979).

Mining also affects the quantity of water in some areas. For example, phosphate mining in Florida lowered the water table 40 feet at some sites, which resulted in the loss of some wetlands and disruption of water flows (NRC 1979). Diversion of water for mining in the West can have an adverse effect on riparian systems.

Although mining operations are regulated to mitigate adverse effects on fish and wildlife, there will be effects on some wildlife and fish because of habitat alteration. Wetlands, riparian systems, and deserts are especially vulnerable. Some wildlife species will be disturbed by the activity associated with mineral development. For example, there is special concern about the potential effects of mining on the grizzly bear population in the northern Rocky Mountains (Matthews et al. 1985). Mining could decrease instream flows in some areas and affect fish and wildlife dependent on riparian habitats and wetlands. When properly reclaimed, some mining sites can contribute improved fish habitat and recreation opportunities. Coal mine pits in the East, for example, may be transformed into fishing lakes, and provide new habitat and recreation opportunities (Stearns 1985).

Local, state, and federal regulators are building mitigation measures into the mining plans over which they have jurisdiction. These efforts, and approved mining operations minimize the impacts on wildlife, fish activities, and habitats.

Local air quality problems can include wind-blown dispersion of radioactive radon gas from uranium mine ore piles, mill tailings, waste dumps, and toxic metals from some other kinds of operations (NRC 1979). There will be some increased hazard to human health from mining. This will result from an inadvertent release of toxics and radioactivity into surface and underground water, wind dispersion and radioactive radon gas, and heavy metals from mine sites (US EPA 1985).

In summary, environmental effects from increased domestic minerals production will occur primarily at the regional and local levels. While there are risks of significant effect in some regions and localities, industry compliance and law or regulation enforcement will reduce these risks.

OPPORTUNITIES FOR MEETING THE NATION'S MINERALS NEEDS

Highlights

- Domestic minerals needs can be satisfied by increased domestic production and imports, extended supplies and materials substitution.
- Opportunities for increased domestic exploration production can be enhanced by improving the business climate, encouraging minerals production on private lands, facilitating minerals development on federal lands, and by improving information on domestic minerals location, quantity and quality.
- Opportunities to increase imports can be improved by tax and trade measures and bi-lateral agreements with foreign nations.
- Supplies can be extended through more efficient recovery in mining and processing, more efficient use in manufacturing and consumption, and recycling.
- There also are opportunities to substitute nonmineral materials, abundant minerals and technology for scarce minerals.

Several numerous opportunities may be available to accommodate the projected increase in the Nation's demands for minerals of all kinds over the next 50 years. They include increasing domestic exploration and production, increasing imports, extending supplies through efficiencies in the extraction and use of minerals and recycling, and substituting abundant minerals and renewable materials or technology for scarce minerals.

Oil imports supplement domestic supplies and the manganese is imported because no economic domestic deposits have been discovered. Molybdenum and construction materials are mined domestically in sufficient amounts to satisfy demand. Large amounts of lead are recycled and per capita consumption of energy has declined through more fuel-efficient autos. Optical fibers (a new technology) are replacing copper in communications.

Increasing Domestic Supplies

Market forces and access largely determine whether ndustry will explore and develop domestic supplies or mport minerals from overseas to satisfy United States lemand. The role of government to stimulate domestic production is limited, yet an array of government poli- ;ies (on taxes, foreign trade, environmental protection, and use of the public lands) influence industry deci- sions. Governments can provide financial incentives to encourage industry to exploit domestic sources but such neasures need to be weighed against social, economic, and environmental objectives.

Improving Business Climate

If domestic minerals are to provide for the Nation's growing demand, industry must be able to explore, levelop, and sell its products at a competitive price with overseas sources. The challenge for industry is to make exploration, extraction, and processing more cost- efficient to offset rising costs (Latimer 1987). Industry has made strides toward reduction of production costs and progress in this area will have to come from indus- ry. However, governments might review tax, trade, and environmental policies to see if they unnecessarily nhibit development of domestic minerals resources and constrain the marketplace. Domestic production can be timulated by tax incentives and low interest loans, as lone in the 1950s and 1960s (McDivitt and Manners 977).

Increasing Mineral Production on Private Land

Decisions on exploration and development of minerals on private land rest with the mining company and the andowner. However, the U.S. Geological Survey can acilitate exploitation of minerals on private lands by ncreased efforts to identify potentially economic leposits of minerals. The U.S. Geological Survey has a geologic map of 17 eastern states that shows the loca- ion of more than 2,200 known deposits of metallic ninerals. This includes a number of strategic minerals hat the United States imports (Federal Emergency Management Agency 1987).

Mineral materials used in construction, such as sand, ravel, and crushed rock, are expensive to transport and usually mined close to where they are used. In many reas of high population growth, mineral materials vital o construction are in short supply and threatened by rban development. There are opportunities for state and ocal governments to use their land use planning and egulatory authority to divert development from areas vith minerals deposits, especially deposits of mineral naterials used in expanded urban construction. For xample, California state legislation encourages local urisdictions to protect high quality deposits of statewide r regional significance (Beeby 1988).

Increasing Mineral Production on Federal Land

Significant supplies of energy, metallic, and some industrial minerals underlie federal forests and rangelands, which include lands in the National Forest System. Key factors are access to the minerals and time required to obtain the necessary approvals and permits. While industry understandably is concerned about constraints on access to minerals beneath federal lands, these lands must satisfy a number of public needs and desires. Congress and land management agencies foreclose or restrict minerals exploration and development in some areas because nonmineral values are higher than the value of the mineral resources. It also is felt that minerals can not be extracted without impairing other values over the long term. For industry, time is money. Timely processing of applications for minerals activity can facilitate exploration and development on lands open to minerals exploration and development. The incentive to invest in domestic exploration and production also can be enhanced by removing some of the insecurity of rights to locatable minerals on public lands (U.S. Congress, Office of Technology Assessment 1979).

Improving Information on Domestic Minerals Resources

Greater efforts to identify areas of high mineralization, with assessment of quantity and quality of promising deposits, will have multiple benefits. Improved information on the quantity, quality, and location of domestic minerals resources, will increase the cost-effectiveness of exploration and development.

Improved information on mineral resources will facilitate advanced planning for development and result in more efficient investment of money and manpower. Advanced planning also might reduce or prevent adverse environmental, social, and economic impacts that generate opposition to some development proposals. Moreover, the identification of specific areas of high potential on public lands might discourage the tendency toward large scale withdrawals of land from mineral exploration and development. Improved mapping on private lands of known deposits or high potential areas can encourage development.

A better base of information might help identify domestic reserves of minerals that are exclusively or substantially imported. The United States probably possesses reserves of important minerals that it now imports from foreign sources. For example, the nation's first platinum and palladium mine opened on national forest lands in Montana in 1987 and decreased U.S. reliance on South Africa for these strategic minerals (Sheppard 1987).

Increasing Research and Development of Technology

New technology will help reduce the cost of exploration and extraction, make domestic minerals more competitive with foreign sources, and make some

uneconomic resources economic. This is particularly true of offshore resources and minerals in seabed crusts that cannot be economically recovered. The Bureau of Mines and U.S. Geological Survey test dredge equipment that will permit sampling of these crust deposits. The Bureau of Mines also is working on technology that will permit recovery of manganese from low-grade domestic resources in case of a supply disruption (Federal Emergency Management Agency 1987). Research also can explore ways to reduce or mitigate adverse impacts to surface resources and the environment and improve reclamation of mined lands. Perhaps this will lessen the opposition to mining as a land use.

Ensuring Emergency Supplies of Critical Minerals

For critical minerals not available domestically or in short supply, domestic needs in time of disruption can be satisfied over the short term by an increase in minerals stockpiles of economic and strategic importance. Further, exploration for domestic supplies can be intensified to find economic and uneconomic sources that can be used in an emergency.

Increasing Imports

For some minerals, such as oil, natural gas, and a number of metallic minerals, the Nation's rising demand can be met by increased imports from foreign countries. While supplies of oil and gas from the Middle East are uncertain, there are secure overseas sources of supply for most metallic minerals. International minerals markets and industry's efforts to reduce domestic production costs will determine the extent that the United States satisfies its demands by increased domestic supplies or imports of foreign minerals. However, the United States will continue to rely on overseas sources for some metallic minerals either because they are cheaper or there are no economic United States deposits. The United States can facilitate overseas imports to satisfy demand through tax and trade measures that encourage United States firms to invest in overseas mines. Trade policies and binational agreements assure stable supplies from countries where the probability of disruption through government policies or regional conflict is low.

Extending Supplies

There are a number of cost-saving opportunities to extend supplies. These include more efficient recovery of minerals and utilization of low-grade ores, more efficient use by manufacturers and consumers, and recycling.

The development and application of technologies that permit greater efficiencies in extraction and processing of raw minerals, with a larger portion of recovered mineral and less waste, is one way to extend supplies. Greater efficiencies in manufacturing, which use less minerals and minimize waste, is another. Consumers can contribute to the extension of supplies by using more efficient products, such as fuel-efficient automobiles and energy-efficient appliances.

Small amounts of minerals that Americans consume are recycled, although the quantity seems to be increasing. Discarded minerals are another possible supply that could extend supplies of raw minerals.

Substituting Nonmineral Materials

The substitution of nonmineral materials, which includes renewable resources, can extend supplies of some minerals. Their special or unique attributes reserve their use. New materials, that combine nonmineral substances with minerals are being developed (Sousa 1987). Thus, composite materials that combine ceramics and polymers with metals are replacing the traditional commodity metals such as aluminum, copper, and carbon steel. Solar energy can be substituted for energy minerals in some applications, and wood substituted in many uses for steel, aluminum, concrete, and plastics. Substitution of renewable resources results in less energy consumed in manufacturing and less pollution.

Greater use of these strategies for extending supplies and substitution will occur if the price of minerals rise. However, use efficiencies and recycling can be facilitated through economic incentives, much as the tax credit for solar collectors stimulated consumer investment in solar as a renewable energy source in the 1970s. Increased research and conservation development, recycling, and renewable resource technologies can reduce costs and environmental risk.

CONSTRAINTS TO IDENTIFIED OPPORTUNITIES

Highlights

- Profitability uncertainty deters investment in minerals exploration and development.
- Information on the Nation's minerals resources is poor.
- There are perceived conflicts between minerals development and other social, economic and environmental objectives.
- Laws, policies, and staff shortages inhibit development of minerals on federal lands.
- Cost and perceived inconvenience discourage efficient use, consumer conservation, and recycling to extend supplies.

There are a number of constraints with the opportunities identified in the previous section. These include marketplace uncertainties, lack of information about the location and quality of domestic minerals resources, uncertainty of foreign supplies of some minerals, and lack of technology for exploration, development, and increased efficiency of use. While significant, most can be overcome.

Investment Uncertainty and Risk

Uncertainties of the marketplace, including price and demand, deter industry investment in domestic resources. There is considerable economic risk in minerals exploration and development. Large amounts of capital are required to find economically developable deposits and open a new mine. Moreover, price and demand can change significantly during the lengthy period between exploration and production. Thus, uncertainty over the potential profitability of a mine can discourage investment in domestic minerals exploration and development.

Volatile world prices contribute to this uncertainty. World prices of most metallic minerals fluctuate widely. While not as volatile as metallic minerals, the price of oil soared in the 1970s, and fell in the 1980s as OPEC nations reduced prices and increased some exports. Market instability is contributed by foreign governments that directly intervene in supply and price decisions. Low prices of foreign minerals and oversupply of some minerals inhibit domestic production, although consumers benefit from cheap overseas supplies. The instability of minerals markets is a significant obstacle to domestic minerals production because of the high cost to find an economic mineral deposit, obtain required government approvals, and the time and cost to develop a mine.

Comparative Costs

Domestic minerals generally cost more to produce because remaining deposits are more costly to find and develop, labor costs are higher in the United States than overseas, and the environmental protection standards are higher. On the other hand, U.S. industry attracts investment because of this Nation's stable government and economy and high quality workforce. As noted earlier, industry has made significant strides to restructure operations and utilize more efficient technology to reduce costs and make domestic supplies more competitive with overseas sources.

Inadequate Information

Insufficient information on the location, quantity, and quality of the Nation's minerals resources are another obstacle in the realization of the Nation's minerals potential. Much of the Nation has not been examined for minerals potential using modern geological and geophysical exploration techniques. About one-half of the Nation is geologically mapped in sufficient detail to provide a sound base for minerals exploration (Cameron 1986).

Development Opposition

There is considerable opposition to minerals development, especially on federal lands. This stems from perceived conflicts with surface land uses, concerns over broader environmental impacts, and state and local concerns that development will impose social and economic stress in possible mining areas. This results in large-scale withdrawals of federal lands from minerals development, and state and local land use controls that restrict minerals activity (American Mining Congress 1987).

Inadequate Management of Minerals on Federal Lands

Laws, policies, and insufficient staff contribute to inefficiencies in the development of mineral resources on federal lands and lost opportunities. Neither industry nor environmentalists appear to be satisfied with the current situation. Areas of adequacy that are challenged today include:

- Low cost minerals available on federal lands which tends to discourage exploration on private land;
- Laws that protect surface resources and the practice to withdraw large land areas (congressionally or administratively);
- Management of minerals on federal lands should be anticipatory, rather than reactive;
- Staff, such as minerals geologists and other specialists, need to plan for minerals development, analyze proposals, and administer minerals operations; and
- Consideration of minerals in federal land and resource management planning.

The statutory framework for minerals exploration contributes to differences in planning for minerals and planning for other resources. One analyst asserts that "for the most part, Congress has chosen to perpetuate an industry and market-oriented regime operating alongside, and many times outside, the renewable resources planning system" (Berck and Dale 1984).

Uncertainty of possession and tenure on public lands also may act to deter exploration and development of minerals. In its 1979 report on the management of minerals on federal land, the Office of Technology Assessment (OTA) concluded that "tenure for minerals activities is uncertain and insecure ... there is no way to obtain exploration rights secure against the government even after particular targets have been staked" (U.S. Congress, OTA 1979). Moreover, OTA found that the laws that exist offer "weak protection against other mineral explorers."

National Minerals Policy

On numerous occasions, Congress has asserted an interest in encouraging and facilitating development of the Nation's minerals resources (American Mining Congress 1987). In 1980, Congress passed the National Material and Minerals Policy, Research, and Development Act. This Act declares that it is the policy of the United States to promote an adequate and stable supply of materials necessary to maintain national security, economic well–being, and industrial production. Appropriate attention should be given to a long-term balance between resource production, energy use, healthy

environment, natural resources conservation, and social needs. However, there remains no definitive policy that describes goals or priorities for the production of domestic minerals. Minerals management is still fragmented among several federal agencies, and coordination is poor (American Mining Congress 1987, U.S. Congress, OTA 1979).

Constraints to Increasing Imports

Major obstacles stem from pressures on the Nation's economy to satisfy the Nation's minerals needs through increased imports. The Nation's balance of payments deficit generates a national interest in domestic materials and products use whenever possible.

In addition, the supplies of some overseas minerals are uncertain because of regional conflict, unstable governments, and the supply and pricing policies of producing nations. Despite the obstacles, there remains a need to develop assured supplies of minerals of economic or strategic importance that are not available domestically or are scarce.

Constraints To Efficiencies in Mining, Use, and Recycling

Major obstacles to increased efficiency in mining, use, and recycling arise from a lack of technology. Technology enables industry to recover a greater proportion of minerals from deposits, and economic and environmentally-sound methods to recover a greater proportion of the base metal from ore. The major obstacle for increased efficiency in the use of metals in manufacturing is cost. As long as supplies of minerals are cheap, there is no incentive to reduce their use in manufactured products or waste. A similar situation exists with consumer efficiency. As long as goods (and energy required to operate them) are inexpensive, there is no reason to conserve. The initial high cost of conversion technology and conservation devices discourages the use of energy conservation equipment. Convenience also obstructs the ability to extend supplies. Disposable items made from minerals are favored for their convenience. Convenience also is a factor inhibiting recycling. Some consumers resist efforts to prepare materials for collection for recycling. Recycling is constrained by lack of technologies for cost-effective collection and processing.

Constraints to Use of Substitutes

Major obstacles to the use of substitutes for some minerals have to do with their suitability for the job—such as weight and durability. Relative cost, in per-unit cost of a product and expense of long-term operation and maintenance, also is a factor. While new, high-technology materials are substituted for traditional commodity metals in many uses, there are no adequate cost-competitive substitutes for minerals for other applications. The use of solar energy, for example, is limited by climatic and cost factors. Wood requires more long-term maintenance than aluminum.

IMPLICATIONS FOR RENEWABLE RESOURCE PROGRAMS

Highlights

- There are opportunities to increase production of minerals beneath the Nation's forests and rangelands, but measures have to be taken to ensure environmental quality is maintained.
- While private lands provide many opportunities for minerals development, there will be increased production on federal lands, including the National Forest System.
- The Forest Service will have to be able to accommodate increased interest in minerals of all kinds on the National Forest System lands.
- This will require improved agency minerals management capability; integration of minerals into planning for all forest resources; review of laws, policies, and regulations; and increased research on ways to develop minerals with minimum impact on surface resources and values.

An increased demand for minerals has significant implications for management of the Nation's forests and rangelands. There are opportunities to increase domestic production of minerals that lie beneath these lands, but increased management is required to ensure that minerals development is compatible with other uses and environmental quality is maintained.

Major opportunities exist to increase minerals production from private forests and rangelands. A large proportion of current minerals production occurs on private land, and there is evidence that major deposits lie beneath private lands in the eastern part of the country. Generally, private land is easier to access. While general environmental quality must be maintained, restrictions on minerals development are not as rigorous as on federal lands where the long-term productivity of other resources are a major consideration.

Increased development of minerals on private lands has major implications for federal agencies. The U.S. Geological Survey provides information on the location, quantity, and quality of the Nation's minerals resources. The Office of Surface Mine Reclamation and Enforcement is responsible for administration of the Surface Mining, Control, and Reclamation Act. State and local agencies regulate specific land uses.

Even if private lands provide the bulk of domestic minerals, there is likely to be increased minerals exploration and extraction on federal lands, including the 191-million acre National Forest System. The national forests and grasslands generally are located in major belts of mineralization, both in the West and East. With some notable exceptions, the national forests now supply a small portion of the minerals produced domestically (table 17) (USDA FS, Minerals and Geology

Table 17. Estimated production of selected minerals on national forest land for 1986 compared to total national production.

Commodity	Units	Forest service production	Total domestic production	% production on NFS lands
Crude Oil	M barrels	18,917	3,168,252	.60
Natural Gas	MM cu ft.	189,663	15,991,000	1.19
Coal	Mston	41,221	890,315	4.63
Uranium	MM lbs.	1.50	13.20	11.36
Geothermal	Kilowatts	17,677	1,580,000	1.1
Lead	metric tons	223,455	353,115	63.28
Phosphate	M metric tons	1,814	38,700	4.69
Copper	metric tons	93,995	1,479,432	6.35
Molybdenum	M lbs.	65,275	93,976	69.46
Gold	M troy oz.	564	3,733	15.10
Silver	MM troy oz.	4,456	34,200	13.03
Sand & Gravel	MM stons	13	883	1.5

Source: USDI BM 1986, USDA FS 1988.

Management Staff 1988). However, the national forests contribute significantly to the Nation's production of molybdenum (69.5% of national production), gold (15.1%), lead (63.3%), silver (13.0%), copper (6.4%), and phosphate (4.7%). In terms of energy minerals, the national forests produced 11.4% of the nation's output of uranium in 1986, only 4.6% of coal, 1.2% of natural gas, and .6% of oil produced domestically. Production, however, is not an accurate indicator of mineral potential because access to federal lands for minerals development typically is more difficult than for private lands, and tenure less certain.

It is known that 6.5 million acres of the National Forest System is underlain with coal, 45 million acres have oil and gas potential, and 300 acres have oil shale potential. Another 300,000 acres have known phosphate potential (USDA FS 1985). *Geologically, the national forests contain some of the most favorable host rocks for mineral deposits.*

With increased demand and favorable markets, interest in minerals underlying the national forests is expected to intensify. For energy minerals, rising prices are likely to result in increased exploration for and development of, oil, gas, coal, and geothermal resources, though uranium activity is questionable. Activity for metallic minerals will continue to be opportunistic and depend on demand and world prices. Development of industrial minerals, such as limestone and phosphate rock, also is likely to increase at a moderate pace. Where construction minerals (crushed rock, sand, and gravel) exist on national forests near expanding population centers, demand for those minerals will intensify. There also is likely to be a growing demand for crushed rock, sand, and gravel from national forests in rural areas for the construction and reconstruction of roads and highways.

In summary, the Forest Service will have to accommodate an increased interest in minerals of all kinds on National Forest System lands. It also will be asked to respond quickly to metallic minerals industry proposals, given the volatility of world markets. The challenge for the Forest Service is to make minerals available from the National Forest System and not compromise other uses and values.

The Forest Service's minerals mission is to "encourage, facilitate, and administer the orderly exploration, development, and production of minerals and energy resources on National Forest System lands to help meet the present and future needs of the nation" (USDA 1986b). Minerals activity should be conducted in an environmentally sound manner, integrated with the planning and management of other national forest resources, and ensure that disturbed lands are reclaimed for other productive uses.

However, the Forest Service cannot create minerals the way it can grow trees. It can affect supply only indirectly by providing access to minerals that underlie National Forest System lands. Its authority varies according to the statutory class of minerals.

The Forest Service has discretion to manage mineral materials (such as sand, gravel, and rock for crushing) as it sees fit. It can sell them, use them for Forest Service projects, provide them free of charge to state and local governments, or not dispose of them at all.

Leasable minerals (fossil fuel minerals in the West, and minerals on acquired land except for common varieties) are made available through decisions to lease made by the Secretary of Interior. Developers can apply for a lease for some areas where they believe minerals exist. The Federal Onshore Oil and Gas Leasing Reform Act of 1987 gave the Secretary of Agriculture (and by delegation, the Forest Service) increased authority to regulate leasing on National Forest System lands. Previously, the Forest Service had only an advisory role, with primary leasing responsibility resting with the U.S. Department of Interior's Bureau of Land Management. The new law provides that the Secretary of Interior cannot issue a lease over the objections of the Secretary of Agriculture and that the Forest Service approve and regulate all surface-disturbing activity that may occur on a lease.

In the case of locatable minerals (generally, metallic minerals beneath public domain in the West), the

Mining Law of 1872 grants miners free access to these minerals. However, later authority gives the Forest Service some control over their development. Control is through construction of roads, effective planning, increased efficiency in processing operating plans, and enforcement of environmental laws and regulations in ways that reduce public opposition and time-consuming appeals and lawsuits.

Improved Minerals Management Capability

Conflicts between minerals extraction and national forest surface resources and uses can be reduced through improved minerals management. With increased minerals activity, more technical personnel are needed to plan for minerals development, participate in interdisciplinary planning teams, review development proposals and prepare environmental and social impact assessments, and monitor minerals exploration, development, and reclamation. The Forest Service currently processes 25,000 minerals cases annually, yet the Forest Service has only 96 minerals geologists and mining engineers (LaMoure 1988).

A resurgence of gold mining activity in the West, and the advent of new processing techniques using toxics to leach the metal from ores, require design and monitoring to ensure that environmental risks are minimized. There also is a need to continue to train personnel with overall responsibility for managing national forests in minerals management to integrate use of minerals resources with management of surface resources, uses, and values.

Integrating Minerals into Land and Resources Planning

The prospect for increased minerals development on National Forest System lands requires improved planning for minerals exploration and development and integration into planning for all the national forests' resources and uses. In 1987, the Bureau of Mines, the U.S. Geological Survey, and the Forest Service entered into an interagency agreement setting policy to conduct mineral resource surveys on National Forest System lands to provide information to develop forest plans.

While it occurs, minerals development displaces some uses of the national forest surface, and requires that choices be made in the allocation of resources. Thus there is the need for information about the value of the mineral resource, surface resources and uses so that comparative values and tradeoffs can be evaluated by the Forest Service and the public. To ensure that these values are adequately considered, and future options not arbitrarily foreclosed, minerals development should be integrated into national forest land and resources management plans. Integrated planning should minimize impacts to surface resources and uses and environmental risks. With careful planning, uses of surface resources can take place as mined land is reclaimed.

Improvements in the Legal and Administrative Framework

Improvements in the legal and administrative framework for minerals management will be required. These include a review of regulations to ensure they are adequate; assignment of full minerals management authority to the Forest Service for the land it manages; and improved procedures for coordination with states, localities, and the minerals industry.

Research Needs

Increased Forest Service research on the economic, social, and environmental impacts that results from minerals development also will be required so adverse effects can be mitigated and positive benefits enhanced. Research needs include methods of exploring and extracting minerals with minimum impacts on surface resources and maintenance of environmental quality; ways to avoid adverse economic and social impacts and to enhance benefits; and techniques to improve reclamation of mined lands.

Alternative Futures

In order to test the sensitivity of possible RPA Program responses to future conditions, the implications of nine alternative futures for U.S. minerals demand and supply are discussed. It should be emphasized that under any of the alternatives, all minerals will not be affected equally. There will be considerable disparity in the effects on energy, individual metallic minerals, and industrial minerals materials.

The projections of this assessment.—Rising prices for energy and metallic minerals will stimulate exploration for, and development of, domestic minerals resources, which includes lowgrade uneconomic deposits. However, increased prices also will stimulate industry to mine and process minerals more efficiently in order to increase production, reduce waste, and cut costs. Rising prices should also result in more efficient use in manufacturing and consumption. While demand for most minerals will continue to grow, it will be moderated by increased use of advanced composite materials, less use of traditional commodity minerals, greater use of renewable resources, and more recycling.

Improved productivity.—As noted above, rising prices will stimulate increased productivity in mining and processing. Industry will leave less mineral in the ground and recover a greater proportion of the minerals from extracted ores. New technology will improve recovery of minerals and permit the economic recovery of lowgrade deposits.

High exports of minerals.—Rising world prices, regional conflict and political instability of source nations, and improved measures that make domestic minerals cost-competitive with overseas sources could stimulate increased U.S. minerals exports. This would

esult in some increased domestic exploration and levelopment. However, for most minerals, exports will epresent only a moderate increase in overall demand or domestic resources.

Shortfalls in discovery of domestic minerals.—The Jnited States has developed easily discovered and recoered minerals resources. Those that remain are of lower uality and more difficult to access using conventional echnology. The pattern is apparent in the case of oil eserves in the Southwest where expensive technology s required to develop remaining oil. Shortfalls in the iscovery of domestic minerals could be met with intenified exploration for hard-to-find deposits, development f low-quality deposits, increased exploration on fedral land, and increased investment in new exploration nd extraction technology.

Intensified minerals management on public and priate lands.—There are national opportunities for intenified minerals exploration and development. As disussed earlier, a number of promising deposits have been dentified in the eastern United States. Major opportuities also exist on federal and private land in the West. Vhether these opportunities are exploited will depend n the world price of individual minerals and the cost o exploit available domestic reserves. Opportunities to xploit minerals on federal lands will be affected by the esignation of additional wilderness areas, the allocaion of other lands for specific uses under the new ational forest land and resource management plans, and vailability of staff to manage minerals.

Changes in land uses that foreclose minerals developnent.—The amount of available land for minerals evelopment could be reduced by expanding urban reas, the designation of additional wilderness, adminisrative constraints on minerals development on federal ands, and state and local land use controls. This would esult in more pressure on lands open to exploration and evelopment, and possibly a reduction in overall domesic production. Urban expansion can significantly affect he availability of construction minerals on private land, nd increase the demand on (and value of) deposits on ederal lands close to metropolitan areas. Sand, gravel, nd crushed rock will have to be transported longer disances, increasing costs to consumers.

Greater environmental constraints on federal ands.—The production of commodities (timber, ninerals, and range forage) are affected by the increase n public interest in noncommodity uses and values of ederal lands. Growing noncommodity and environmenal concerns can sharply reduce the production of ninerals on federal lands. This will require that the 'orest Service integrate minerals development with ther uses of the national forests; protect the scenic, ecreation, water quality, and wildlife values; and mainain the quality of the forest environment.

Reduced consumption of minerals.—A number of levelopments in combination can reduce the demand or some minerals, particularly gas and oil, uranium, and ome of the traditional metallic minerals. Possible levelopments include a significant rise in world prices f individual minerals, greater use of high-technology composite materials, environmental and safety concerns, the use of renewable resources, and recycling. While demand for some minerals will fall under this scenario, the demand for others (specialty metals such as the platinum group metals, gold and silver, magnesium, and titanium) will rise substantially.

Increased consumption of domestic minerals.—Events could occur that will result in increased demand for some domestic minerals. If, for example, foreign oil producing nations agree to a sharp reduction in production, the resulting rise in prices can stimulate increased production and consumption of domestic oil. Political instability or social unrest can cut off supplies of other important minerals, which increases U.S. reliance on domestic supplies. This will result in increased exploration for, and development of, domestic supplies, and the development of new technology for the recovery and processing of uneconomic reserves of critical minerals.

Policy Questions for Forest Service Programs

The implications of this analysis of the minerals situation in the United States raises a number of public policy questions for the Forest Service. They can be expressed in terms of five questions.

1. To what degree should the Forest Service encourage the exploration for, and development of, minerals, especially metallic minerals, on the National Forest System lands?

Historically, the Forest Service has done little to encourage minerals development on the national forests. The 1872 Mining Act declared the federal domain open to legitimate metallic minerals exploration and development. Forest Service policies and programs are aimed at accommodating mining activity. Generally, the Forest Service has sought to maintain access to national forest lands for minerals development, but made no overt moves to encourage exploitation. Since manufacturers draw from domestic and overseas sources influenced by price, consumers generally benefit by getting the least cost product. However, by encouraging and facilitating minerals development on the national forests, the Forest Service might help reduce price volatility in some market situations.

There are actions the Forest Service can take to encourage and facilitate minerals development on the national forests. The Forest Service can, for example, delineate lands of high minerals potential as special "minerals zones" in national forest land management plans. In these zones, minerals would be considered the primary value, much as recreation is determined the primary value of some areas. It could increase staff capability and develop procedures to expedite reviews of mining plans and the granting of necessary permits and approvals.

There is, however, substantial and growing opposition to mining on the national forests. Opponents contend that mining diminishes the value of large areas for other uses and creates significant environmental

problems. These interests want even tighter controls on mineral development on the national forests.

The emphasis to be given minerals development on the national forests should be addressed in the RPA Program.

2. Should miners be required to pay fair market value for minerals on public lands?

Under terms of the 1872 Mining Law, discoverers of metallic and other valuable minerals are given the right to patent their mining claims on which they have perfected a discovery of such minerals. On the lands where the 1872 Mining Law applies, this can result in the conversion of property from the federal government to the mining claimant. Nominal fees are involved in such transactions. For energy minerals, the federal government receives revenue from annual rentals of the acreage involved and royalties based on production. For mineral materials, sales rates are established by appraisals conducted for the local market area. A policy to charge fair market value for minerals extracted from federal land would have a number of effects. It can discourage some minerals activity on federal land, an effect that would be applauded by opponents of mining on the national forests. On the other hand, such a policy probably would result in increased costs to consumers for some minerals. Moreover, to the extent that charges for minerals taken from federal lands made domestic minerals noncompetitive with overseas sources, both the Nation's gross national product and balance of trade would be negatively affected.

Major and controversial changes in law would be required to permit the Forest Service to charge fair market value for minerals other than mineral materials extracted from the national forests. However, this issue warrants further consideration in the RPA Program.

3. What should the Forest Service do to assure that environmental quality is not impaired as a result to minerals development?

Mining can have a significant effect on the quality of the environment, although technology is available to mitigate most of the adverse impacts. The Forest Service devotes considerable attention to assure that mining is carried out in ways that minimize short-term impacts and results in no irreversible adverse effects to the environment. However, increases in mining activity, and the use of new technologies, require that the Forest Service have the personnel and funds to review minerals development plans and adequately monitor minerals extraction, processing, and mined-land rehabilitation on the national forests. The RPA Program should address Forest Service programs that protect the environment from the adverse impacts of mining and ways to assure that manpower and funding levels are adequate for the task.

4. To what degree should the Forest Service insulate local communities against the potentially destabilizing social and economic effects of minerals development?

Large-scale minerals development can have both positive and negative effects on communities where mining takes place. Usually, the negative effects occur at the outset of development—large numbers of workers may be attracted to areas not prepared for a major population boom—and again years later as mining activity winds down and ultimately ceases. This deprives a community of an established and substantial industry.

Volatile prices in the minerals industry contribute to short-term disruptions in local economies. Prices that move substantially in a month or two result in swift and major changes in industrial activity—changes felt in local economies, in employment levels, income, consumer spending, and property values. For example, changes in oil prices or production levels from Middle Eastern countries provoke major and rapid changes in exploration and extraction activities in "oil patch" towns in Louisiana, Texas, and Oklahoma. Changes in drilling plans affect leases and purchases in everything from rigs to drilling fluids, catering and transportation services. Employment levels and real estate prices also follow the "boom or bust" cycle. Worker mobility in the oil industry reduces community cohesion; local government service levels rarely adjust fast enough to meet needs. State economies are not immune. Cutbacks in employment and spending increase unemployment compensation costs while reducing income from income and sales taxes. States, that levy severance taxes per barrel and per thousand cubic feet (Louisiana) see those revenues fluctuate as output levels move following price changes.

It is not clear just what alternatives exist for the Forest Service to assist communities in dealing with the negative social and economic effects of mineral activity, but the issue should be addressed in the RPA Program.

5. Should the Forest Service promote more efficient use of minerals in production, processing and manufacturing, and the use of renewable resources, substitutes, and recycling to extend supplies of minerals and reduce pressure to produce on the national forests?

Market forces largely determine the extent to which the mining industry employs more efficient recovery and processing technologies, or the extent to which manufacturers and consumers substitute other materials or recycle. In the case of wood, the Forest Service explicitly promotes more efficient utilization of timber on the national forests, and has research programs intended to extend supplies, so as to slow the rate of increase in the price of timber products. The RPA Program should consider whether the Forest Service could play a constructive role to promote alternatives in the use of minerals.

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Forest Service Regions and Assessment Regions

United States
Department of
Agriculture

Forest Service

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General Technical
Report RM-180

An Analysis of the Range Forage Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Linda A. Joyce

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 476, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
General Technical Report RM-180

October 1989

An Analysis of the Range Forage Situation in the United States: 1989–2040

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Acknowledgments

A report of this magnitude is necessarily the result of many people's efforts. The economic analysis of future forage demand was made by Dr. C. Kerry Gee, retired Economic Research Service, USDA, and Dr. Al Madsen, Colorado State University, using livestock projections made by William Quinby, Economic Research Service, USDA. The cooperation of Robert Williamson and the Range Management Staff, USDA Forest Service, facilitated the public forage supply analyses. In particular, Edward Schlatterer helped access data and source material, collaborated in writing chapter 7, and reviewed all chapters. Edward Frandsen determined current range forage values. These latter analyses benefited from research by Terry Crawford, Economic Research Service, USDA. Amalgamating inventory information was facilitated by the cooperation of the regional Range staff directors of the USDA Forest Service; Willie Peterson, Bureau of Land Management; and David Chalk, Thomas Shiflet, Don Pendleton, William Maetzold, Soil Conservation Service. The evolution of written material was helped greatly by the reviews of Dr. Thomas Quigley, Dr. Fee Busby, Dr. Bill Krueger, Dr. Arden Pope, Dr. Henry Pearson, Dr. Earl Aldon, Dr. Gale Wolters, and Ron Michaeli. A special thanks is extended to Terri Tucker Schulz who managed the assessment data and contributed to the discussion of riparian management. Many thanks go to Karen Omeg, and Marj Swanson for typing and retyping tables. Coordination of assessment activities was greatly helped by the experience of the RPA staff, Forest Service, most particularly, Adrian Haught and Dave Darr. Charged with similar objectives of assessing natural resources, the colleagiality of Thomas Hoekstra, John Hof, and Curt Flather made life seem endlessly creative when new research ideas were cast up and carried the day when deadlines were to be met.

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An Analysis of the Range Forage Situation in the United States: 1989–2040

Linda A. Joyce

CHAPTER 1: THE RANGE RESOURCE

INTRODUCTION

Range and range resources are many things to many people. In the broad view, range is a type of land, a kind of vegetation, and a way of management (Range Inventory Standardization Committee 1983, U.S. Senate 1936). Previous studies or assessments on the Nation's range resources have had broad objectives, such as the Forest-Range Environmental Study (USDA Forest Service 1972), or the 1980 Assessment (USDA Forest Service 1980), or have focused on specific issues, such as range condition (U.S. General Accounting Office 1988).

The mandate for the present assessment is the Resource Planning Act (RPA) of 1974 which directs the Forest Service (FS) to prepare an Assessment of the Nation's renewable resources every 10 years. As directed by this legislation, the assessment shall include but not be limited to "an analysis of present and anticipated uses, demand for, and supply of the renewable resources, with consideration of the international resource situation, and an emphasis of pertinent supply and demand and price relationship trends".[2] The present report analyzes the range resource from a national perspective, includes public and private lands, and uses information collected by other public agencies as well as the Forest Service.

Chapter 1 describes the current status of the range resource, the multiple outputs currently produced from range vegetation, the land area and productivity of range vegetation. The factors affecting supply and demand of range outputs (Chapters 2 and 3) are used to develop a projection of future supply and demand (Chapter 4). The social, economic, and environmental implications of this future scenario are reviewed in Chapter 5, opportunities for and obstacles to managing the range resource are discussed in Chapter 6, and the implications to all Forest Service programs, including the National Forest System (NFS) renewable resource program, Research, and State and private forestry programs are discussed in Chapter 7. Terms used in this report are defined in the Glossary (Appendix D). Scientific and common names for all plants mentioned in this report are given in Appendix A. Scientific and common names for all animals mentioned in this report are given in Flather and Hoekstra (in press).

[2]*Forest and Rangeland Renewable Resources Planning Act. Act of Aug. 17, 1974. 88 Stat. 476, as amended; 16 U.S.C. 1600-1614.*

Four Assessment regions are used to present resource data: the Northern (NO), Southern (SO), Pacific Coast (PC), and Rocky Mountain (RM). For the present report, a finer delineation of the western regions is used, where possible (fig. 1). The Pacific Coast region is broken into the Pacific North (PN) and California (CA) regions. The Rocky Mountain is broken into the Northern Rocky (NR) Mountain and the Southwest (SW) regions. Alaska and Hawaii are treated separately.

RANGE AND RANGE RESOURCES

Range vegetation is defined as grasses, grass-like plants, forbs, and shrubs. This definition includes introduced species that are managed like native plants. When the vegetation (climax or natural potential) is dominated by range vegetation, the land is referred to as rangeland. Whereas rangelands predominate in western United States as natural grasslands, shrublands, savannas, deserts, tundra, alpine, coastal marshes, and wet meadows, rangeland also occurs as tallgrass prairie, marshes, and wet meadows in eastern United States. Riparian ecosystems, and plant communities dominated by introduced species are also considered rangelands. Range vegetation is most commonly associated with grasslands and shrublands, but forest lands also support an understory of grasses, grass-like plants, forbs, and shrubs. Range vegetation forms the basic building block in the production of multiple resources from forest and rangelands.

In this document, the diversity of vegetation on forest and rangeland is described using the 34 ecosystems of the Forest and Range Environmental System (FRES) (fig. 2, table 1). This classification system is based on broad groupings of the Küchler (1964) communities and forest and woodland types from the FS survey (USDA Forest Service 1967). The mountain meadow vegetation type, an important forage source, was added to Küchler's system and this amended classification was renamed *Potential Natural Communities* (PNC) to mark the distinction from Küchler's classification (Mitchell and Joyce 1986). The PNC represents the biotic community that would become established if all successional sequences proceeded without interference by humans under the

Figure 1.—Assessment regions of the United States.

Source: Garrison and others.

Figure 2.—FRES ecosystems of the United States (see table 1 for explanation of numerals).

present environmental conditions (Range Inventory Standardization Committee 1983). A brief description of each FRES ecosystem is given in Appendix B.

Climatic, geological, and elevational differences across the United States result in the diversity of ecosystems from spruce-fir in Maine, to wet grasslands in Florida, and to chaparral mountain shrub ecosystems in California (fig. 2). For areas in the western United States, the environmental heterogeneity of the landscape induces a mixture of ecosystems within a short geographic distance, necessitating a listing of these types, rather than a finer delineation in figure 2. The diversity of vegetation across the nation's landscape gives an indication of the diversity of renewable resources from forest and rangelands.

Table 1.—Explanation of FRES ecosystems shown in figure 1.

Number	Ecosystem	Number	Ecosystem
10	White-red-jack pine	27	Redwood
11	Spruce-fir	28	Western hardwoods
12	Longleaf-slash pine	29	Sagebrush
13	Loblolly-shortleaf pine	30	Desert shrub
14	Oak-pine	31	Shinnery
15	Oak-hickory	32	Texas savanna
16	Oak-gum-cypress	33	Southwestern shrubsteppe
17	Elm-ash-cottonwood	34	Chaparral-mountain shrub
18	Maple-beech-birch	35	Pinyon-juniper
19	Aspen-birch	36	Mountain grasslands
20	Douglas-fir	37	Mountain meadows[1]
21	Ponderosa pine	38	Plains grasslands
22	Western white pine	39	Prairie
23	Fir-spruce	40	Desert grasslands
24	Hemlock-Sitka spruce	41	Wet grasslands
25	Larch	42	Annual grasslands
26	Lodgepole pine	43	Alpine

[1]*Not mapped.*
Source: Garrison et al. 1977.

MULTIPLE RESOURCE PRODUCTION ON FOREST AND RANGELANDS

The many products flowing from management of the Nation's forest and rangelands are not independent of nor are they produced in constant relation to each other. This relation can best be described as joint production, wherein multiple inputs are combined to produce multiple outputs. The management of these multiple inputs to produce these multiple outputs is range management. Range management includes:

— determining suitability of vegetation for multiple resource uses;
— designing and implementing range vegetation improvement practices;
— understanding social and economic effects of management alternatives;
— controlling range insects;
— determining wildlife, recreational, wild horse and burro, and livestock carrying capacities;
— protecting soil stability;
— reclaiming disturbed areas;
— designing and controlling livestock management systems;
— managing and controlling undesirable range vegetation;
— coordinating management activities with other land and resource managers;
— maintaining environmental quality including soil, water, and air (USDA Forest Service 1987c).

Forage is browse and herbage which is available and may provide food for grazing animals or be harvested for feed (Range Inventory Standardization Committee 1983). Range is commonly perceived as producing only forage for livestock. Although livestock grazing is an important use of grazinglands, both forest and rangeland, livestock grazing is not the only use and in some parts of the world is not the most important or best economic or social use of rangelands (Busby 1987). Range outputs and range management are broader issues than domestic livestock. The diversity of outputs from range ecosystems includes forage for both domestic and wild herbivores, firewood and specialty wood products, seed sources for agricultural or reclamation or landscaping purposes, minerals, water quality and quantity, air quality, open space, threatened and endangered plants and animals, genetic material, recreational use, plant and animal diversity, human community stability, and scenic quality. All plant and animal species that depend on rangeland or range vegetation are dependent on range management and must be considered as a product or output of range management. The production of timber and range vegetation, or wild and domestic herbivores, are interdependent in that the management for one output affects the yield of the other. Thus, the management of the Nation's forests and rangelands must recognize tradeoffs or enhancements across resource production opportunities (Hof and Baltic 1988).

The importance, and ultimately the use, of rangelands is often determined by cultural factors in society (Box 1988). Hunter-gather societies and pastoral economies value food production from rangelands. Urban societies value rangelands and forests for clean water production and recreation opportunities. Increased human densities in developed countries raise the question of waste disposal on rangelands while placing a higher value on wilderness for recreation. To reach and maintain these desired objectives while protecting fragile soils and watersheds, the managers of range vegetation must apply knowledge, skills, and techniques based on ecological principles. The joint products that result from range management are important outputs that need to be recognized as goals, objectives, benefits, and uses of the range

resource. A review of some of the current outputs from rangelands and forests follows.

Agricultural, Reclamation, and Landscaping Uses of Range Plants

Interest in the harvest and cultivation of native plants is increasing as society seeks less water-consuming or low maintenance plants for agriculture, land reclamation, and landscaping (Aldon et al. 1987, Goodin and Northington 1985, Hinman 1984, Patton et al. 1986). Range plants are harvested or cultivated for oil, rubber, fruits, vegetables, nuts, grains, medicines, ornamentals, firewood, and specialty wood products (table 2). Cacti are utilized for fruit, green vegetables, forage, fodder, gums for adhesives and thickening foods, strong fibers and ornamentals (Russell and Felker 1987, Vietmeyer 1986). The harvest of prickly pear cactus fruit in Mexico is more than twice the world's harvest of apricot, papaya, strawberries, or avocados (Vietmeyer 1986). Seed from jojoba, a southwestern shrub, yields a valuable lubricating oil (fig. 3). In 1986, the combined harvest of jojoba seed for the United States, Mexico, and Israel was 820 metric tons; a substantial increase over the 12 metric tons harvested in 1976 (Gillis 1988). Guayule, another southwestern shrub, has supplied significant quantities of rubber during previous world wars (Foster and Moore 1987); other plants such as buffalo gourd, gopher plant, and gumweed offer possible sources for oil or rubber (Hinman 1984, Hoffman and McLaughlin 1986, Johnson and Hinman 1980, Patton et al. 1986). Increasing numbers of urban centers in the western United States encourage the use of xeric landscaping to reduce water use. Water use efficiency is much greater for some native plants than plants traditionally used

Table 2.—Resource outputs from range ecosystems.

FRES ecosystem	Plant value	Herbage production (pounds per acre)	Large herbivores	Threatened and endangered animal species
Sagebrush	Forage, browse	0–2,000	Deer, pronghorn, wild horses and burros, sheep, cattle	Utah prairie dog
Desert shrub	Mesquite-fuelwood, charcoal, forage, browse, ornamental cactus, rubber, oil	0–1,000	Deer, pronghorn, bighorn sheep, wild horses and burros, sheep, goats, cattle	Masked bobwhite Sonoran pronghorn
Shinnery	Forage, browse	500–2,000	Deer, cattle	
Texas savanna	Mesquite-fuelwood, charcoal, forage, browse, rubber	0–3,000	Deer, cattle, sheep, goats	Jaguarundi Ocelot Northern aplomado falcon
Chaparral-mountain shrub	Acorns, forage, browse	0–2,000	Deer, wild horses and burros, goats	California condor San Joaquin kit fox
Pinyon-juniper	Christmas trees, fuelwood, pine nuts, fence posts, chips, forage, browse	0–800	Deer, elk, cattle	Thick-billed parrot
Mountain grasslands	Forage	1,000–2,000	Deer, elk, pronghorn, cattle, sheep	
Mountain meadows	Forage	0–4,000	Deer, elk, moose, cattle	
Plains grasslands	Wildflowers, landscaping, forage	0–2,000	Deer, pronghorn, cattle, sheep	Black-footed ferret Northern swift fox
Prairie	Wildflowers, landscaping, forage	1,500–6,000	Deer, pronghorn, cattle	Attwater's prairie chicken Northern swift fox Red wolf
Desert grasslands	Ornamental cactus, landscaping, forage	0–1,000	Pronghorn, deer, cattle, sheep	Masked bobwhite
Wet grasslands	Forage	0–12,000	Deer, cattle	Everglades kite Whooping crane Attwater's prairie chicken
Annual grasslands	Forage	0–4,400	Deer, wild horses and burros, cattle	San Joaquin kit fox Giant kangaroo rat
Alpine	Forage	0–1,200	Deer, elk, bighorn sheep, sheep	Grizzly bear

Figure 3.—Jojoba growing in association with saguro and cactus on Southwestern rangelands.

in urban landscaping (Front Range Xeriscape Task Force [n.d.]). Ecosystems particularly valuable for their landscaping resources are the prairie, plains and desert grassland ecosystems (table 2).

Initially, native seed sources or plants had been difficult to obtain because so little commercial work with arid species had been done. Mined land reclamation research has increased the availability of seed and plant sources. Government conservation programs that encourage the planting of cropland into native range also increase the demand for native plant seeds (Hijar 1988). Commercial nurseries offer an increasing number of native grasses, forbs, shrubs, and trees capable of withstanding long periods of dry weather (Diekelmann et al. 1986, Wallace et al. 1986).

Forage for Wild and Domestic Herbivores

Herbivores, animals that feed on plants, include wildlife such as elk, deer, and antelope, and livestock such as sheep, horses, goats, and cattle. Nearly all forest and rangeland ecosystems provide forage for wild and domestic herbivores. Forage production varies from less than 200 lbs/acre in dense forest stands (table 3) to greater than 2,000 lbs/acre in many grassland ecosystems (table 2). Greater numbers and more diversity in wild and domestic herbivores are found in ecosystems that provide greater amounts of forage and browse.

At least part of the feed mix for domestic horses, sheep, cattle, and goats and all of the feed mix for wild herbivores is forage produced on pasture, range, or forest land. Grazed roughages are forage harvested by grazing or browsing forest, rangeland, or pasture whereas harvested forages are mechanically harvested from pasture, haylands, or croplands seeded to forage crops. Harvested forages are important in providing feed for livestock during winter when little grazed roughages are available, or when forage is not readily accessible, such as for recreational horses in suburban areas. Harvested forages and stored crops are also used by wildlife as a source of winter feed (Schneidmiller 1988).

While the exact forage demand will vary by type and age of animal, population estimates of wild and domestic herbivores can be viewed as an indication of forage demand. The total number of cattle and calves for dairy and beef in 1985 was 105 million. Sheep numbers were 8.4 million and goats were about 1.6 million. The 1982 Census of Agriculture (USDC Bureau of Census 1984) reported approximately 2 million work horses on farms in the United States. Horses are increasingly becoming a recreational animal. Peat et al. (1987) estimated 5 million horses, predominately recreational stock, and the

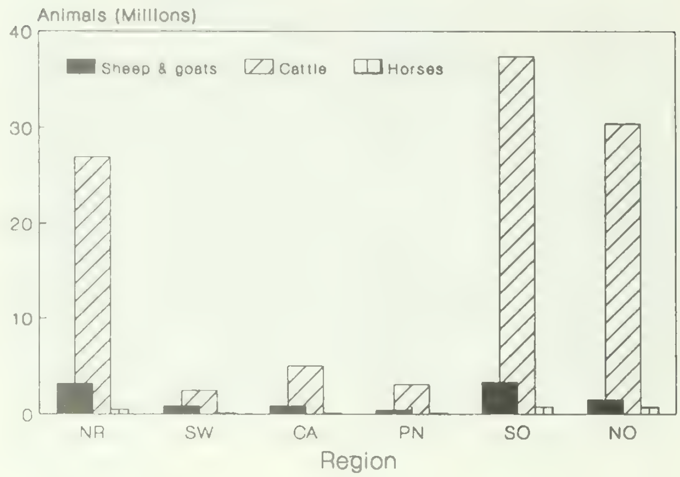
Table 3.—Resource outputs from western forest ecosystems.

FRES ecosystem	Plant value	Herbage production (pounds per acre)	Large herbivores	Threatened and endangered animal species
Douglas-fir	Timber, forage, browse	50–1,400	Elk, deer, moose, sheep, cattle	Gray wolf Woodland caribou
Ponderosa pine	Timber-framing, millwork, forage, browse	50–1,200	Deer, elk, cattle	New Mexico ridge-nosed rattlesnake
Fir-spruce	Timber	100–900	Elk, deer, moose, mountain goats, bighorn sheep, cattle	Woodland caribou Grizzly bear
Hemlock-Sitka spruce	Timber	0–400	Elk, deer, moose	Columbian white-tailed deer
Western white pine	Timber	0–400	Elk, deer	
Larch	Timber	0–3,000	Elk, deer, moose, cattle	Woodland caribou
Lodgepole pine	Timber, forage, browse	40–2,300	Elk, deer, moose	
Redwood	Timber		Elk, deer	
Western hardwoods	Timber-paper, landscaping	1,400–2,000 500–4,000 (Aspen)	Deer, elk, cattle, sheep	California condor Columbian white-tailed deer

1985 United Nations Production yearbook (Food and Agriculture Organization 1986) reported 10.6 million horses in the United States. Numbers of white-tailed and mule deer are estimated to be over 16 million, pronghorn antelope over 700 thousand, and elk over 460 thousand (Council for Agricultural Science and Technology 1986). Smaller numbers of moose, bison, wild sheep, and mountain goats are also found in the United States (Flather and Hoekstra in press).

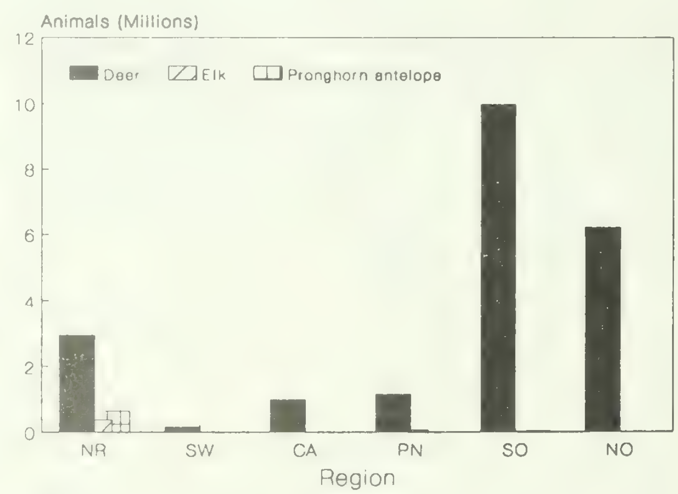
Demand for grazed roughages exists in every region of the United States (fig. 4). Large numbers of wild and domestic herbivores are found in the SO, the NO and the NR region. Deer and cattle are the most numerous herbivores in these regions. The NR region has the largest number of sheep, and the SO region, primarily Texas, has large numbers of goats.

(a) Sheep, goats, cattle, and horses



Source: cattle and sheep: USDA, (1987); horses and goats: USDC, Census of Agriculture (1983)

(b) Deer, elk, and pronghorn antelope



Source: Council for Agricultural Sciences and Technology (1986)

Figure 4.—Number of large herbivores by assessment regions.

Threatened and Endangered Plant and Animal Species

About 25,000 species, subspecies, and varieties of plants are native to the United States. The Center for Plant Conservation estimates that 680 of these plant species will be extinct in the United States by the year 2000 (Center for Plant Conservation 1988). Under the Endangered Species Act of 1973, federal agencies must ensure that their management actions will not jeopardize the existence of a threatened or endangered plant or animal species. As of July 1988, 185 plant species officially were classified as threatened (147) or endangered (38) (Appendix C). Threatened and endangered animal species can be found on most forest and rangeland ecosystems (tables 2, 3, and 4).

Although grazing pressure has been a concern, 25 species of the last 28 plant species officially listed as threatened or endangered were recognized because of increased human disturbance, either trampling, collecting, off-road vehicle use, road construction, quarrying, or deforestation. The most significant threat to the future existence of plants such as endangered cacti (fig. 5), however, is amateur and commercial collecting (Wright Fishhook Cactus Recovery Committee 1985). Recovery plans for restoring endangered or threatened plants had been approved for 70 plants as of July 1988 (USDI Fish and Wildlife Service 1988).

Wildlife

Wildlife and fish contribute to the functioning of ecosystems in roles such as pollination, seed dispersal and germination, nutrient cycling, and herbivory (Flather and Hoekstra in press). During some part of the year, rangeland ecosystems are associated with 84% and 74%, respectively, of the total number of mammal and avian species found in the United States (Flather and Hoekstra in press). Familiar rangeland species include big game such as pronghorn antelope, small game such as jackrabbit and sage grouse, nongame such as horned lark. Species mobility, public ownership, and state and federal authority for management contribute to the complexity of wildlife and fish management and this complexity increases the importance of cooperation among the public and the managing agencies (Flather and Hoekstra in press).

Forest and rangelands provide food, cover, and water for wildlife (tables 2, 3, and 4) and changes either in the quantity or quality of habitat affect wildlife populations. Wildlife, if associated with specific habitats, are sensitive to changes in those ecosystems, as seen in the declining numbers of the long-billed curlew and the

Table 4.—Resource outputs from eastern forest ecosystems.

FRES ecosystem	Plant value	Herbage production (pounds per acre)	Large herbivores	Threatened and endangered animal species
White-red-jack pine	Timber	0–400	Deer, moose	Eastern timber wolf Kirtland's warbler
Spruce-fir	Timber	0–800	Deer, moose	Eastern timber wolf Woodland caribou
Maple-beech-birch	Timber	0–800	Deer, moose	Eastern timber wolf
Aspen-birch	Timber	0–400	Deer, moose, cattle	Eastern timber wolf
Oak-pine	Timber, acorns	50–500	Deer, cattle	Eastern cougar
Oak-hickory	Timber, acorns	200–3,000	Cattle, deer	Red wolf Northern flying squirrel
Loblolly-shortleaf pine	Timber, forage, browse	0–1,800	Deer, cattle	Red-cockaded woodpecker
Longleaf-slash pine	Pulp, paper, forage, browse	120–2,600	Deer, cattle	Red-cockaded woodpecker Florida panther
Oak-gum-cypress	Acorns, timber, forage, browse	0–2,000	Deer	Key deer Ivory-billed woodpecker Bachman's warbler Red wolf
Elm-ash-cottonwood	Forage	0–800	Deer, cattle	Eastern timber wolf

reduced area of shortgrass prairie (USDI Fish and Wildlife Service 1982). Lakes and ponds scattered across rangelands, especially in the Great Plains, are important nesting and wintering areas for waterfowl, and intensification of land use, either by grazing or agriculture, can degrade these waterfowl habitats. Two critical issues with respect to wildlife habitat on rangelands include the reduction of area and fragmentation of grassland habitats in the East, and the degradation of riparian habitats in the arid West (Flather and Hoekstra in press).

Wild Horses and Burros

The passage of the Wild Free-Roaming Horses and Burros Act of 1971 delegated authority and responsibility to the Secretaries of Interior and Agriculture for the protection, management, and control of wild free-roaming horses and burros on lands administered by the Bureau of Land Management (BLM) and the Forest Service. Only those public lands are considered in this Act. Wild horses and burros can be found in the many western ecosystems (table 2). Although the greatest number occurs in Nevada, wild horses are also found in California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, and Wyoming. The largest numbers of feral burros occur in Nevada, California, Utah, and Arizona but they are also found in Idaho, New Mexico, and Oregon. Current estimates indicate that the appropriate management levels for FS and BLM-administered lands is under 28,300 wild horses and 3,500 burros. In 1988, over 39,000 feral horses and 5,000 burros were found on FS and BLM-administered lands (USDA Forest Service and USDI Bureau of Land Management 1989). Since 1972, 81,000 animals have been placed through the federal adoption program.

Exotic Animals

The importation of exotic animals, either purposely or accidentally, has a long history in the United States. Some introductions, such as the ring-necked pheasant and the chukar, are considered beneficial, whereas other introductions, such as the Norway rat, are considered detrimental. Since the early 1900s, the number and type

Figure 5.—San Raphael cactus (*Pediocactus despainii*), an endangered cacti, is found in Utah (photo courtesy of Dr.—Kenneth Heil, San Juan College).

of exotic herbivores have continually increased (Doughty 1983). Whereas ranchers originally introduced these animals as attractions, big game ranching has expanded into meat production, live animal sales to zoos or other game ranches, hunting opportunities, and recreational experiences for tourists such as viewing parks. Numbers of some species are now greater in the United States than in their country of origin, and interest in breeding these animals on ranches for zoos has increased (U.S. Congress, Office of Technology Assessment 1986a). Exotic animals are found in large numbers in Texas, but also occur in other states. Exotic animals have been harvested in 22 states (Temple 1982 as cited by White 1987) and membership of the Exotic Wildlife Association in 1985 was 192 members in 18 states (Nicholl 1985, personal communication cited in White 1987).

Water

All range and forest lands function as watersheds that drain into either aquifers or aboveground water storage for agricultural, industrial, municipal, recreational, and navigational uses. High-elevation watersheds are primary water-producing areas in both eastern and western United States. Low-elevation watersheds, used primarily for livestock grazing, contribute little to water quantity, but are important in terms of water quality (Tiedemann et al. 1987). Water management policy has traditionally assumed that the supply of water is a fixed constant (Conservation Foundation 1987). Climate, one of the natural determinants of water quantity, is a dynamic process. Improved analyses of the historical variabilities in climate and the recently recognized potential impacts of human societies on future climate are causing a new awareness of the dynamics of water production (Waggoner 1988). The future management of forest and rangelands will increasingly focus on water production, storage, and water quality (Dixon 1983, Guldin in press, Smith et al. 1987, U.S. Congress, Office of Technology Assessment 1983).

Riparian zones, significant to wild and domestic herbivores, are also important in maintaining water quality, the fisheries resource, and water-oriented recreation such as fishing, kayaking, white-water rafting, or boating (Flather and Hoekstra in press, Guldin in press, U.S. Congress, Office of Technology Assessment 1983). Riparian habitats are extremely productive systems with interchanges of energy, nutrients, and biotic material between the aquatic systems on their inner boundary and the upland range systems on their outer boundary (Kauffman and Krueger 1984). Riparian habitat deteriorates under overgrazing and may be lost when the land is converted to agricultural use, or the stream is channelized for flood control or is flooded for water storage. Where water development changes the flow velocity or periodicity, riparian zones may increase (Skinner 1986). Vegetation management within the riparian zone requires the consideration of the desired use of the area (Skovlin 1984).

Recreation and Scenery

Recreational opportunities on rangelands include nonmotorized recreation such as hiking, horseback riding, picnicking, and skiing, and motorized recreation such as snowmobiling and use of off-road vehicles. Increasing demand for outdoor recreation places pressure on range and forest ecosystems to supply high quality recreational experiences. The long-term protection of recreation resources and open space is one of the high-priority issues facing state recreation agencies (Cordell in press). Demand for recreation is greatest near population centers. Ranching operations are important in maintaining open space in California (Huntsinger 1988). Improved coordination among public agencies, private groups, and industry is seen as a way to more efficiently provide future recreational experiences, facilities, and services on federal and private lands (Cordell in press).

The demand for horseback riding, a significant recreational use on NFS lands, is projected to almost double by 2040 (Cordell in press). Horse-riding activities are associated with private individuals and their own horses, with large groups from lodges adjacent to NFS lands, and with hunting parties led by outfitters (fig. 6). In terms of grazing use, the number of recreational stock is small compared with permitted livestock. Nonetheless, these recreational stock numbers offer some insight into the significance of this form of recreation. In 1986, over 45,000 Animal Unit Months (AUMs) of free recreational stock use were estimated to have occurred on NFS lands across the western United States (USDA Forest Service 1987b). Over 100,000 horses and burros were involved in this use.

Recreational opportunities on private lands have been developed to varying degrees across the United States. The first organized effort to capture additional income from Texas rangelands occurred in 1941 with the development of the Edwards Plateau Game and Wildlife Management Association (Berger 1973). Since then, the leasing of lands for recreational purposes such as hunting has grown, particularly in Texas (Pope and Stoll 1985, Pope et al. 1984a). Other opportunities developing in the private sector on ranches include hunting, fishing, swimming, horseback riding, hiking, camping, cross-country skiing, snowmobiling, photography, historical and geological tours, and bed and breakfast operations with the opportunity to participate in the working of the ranch (USDA Soil Conservation Service 1987c, Wyoming Farm Bureau 1987). Access to water for recreational fishing or boating is also producing income for private ranches.

Clearly the provision of recreation use in an area and how recreationists perceive their experience is influenced by the management of all range resources. Recreation use can impact the vegetation in a number of ways, such as harvesting of plants, trampling, erosive damage to hillsides, or braiding of roads and trails (Andrews and Nowak 1980, President's Commission on American Outdoors 1986). The degree of impact varies with the kind and intensity of recreational use and with environmental factors such as soils, and topography (Payne et al.

1983, Summer 1986). Many range ecosystems provide recreation along with grazing or timber outputs. A majority of recreationists interviewed in the Pacific Northwest indicated that their use of recreational areas would be altered if management intensity increased or became more apparent (Sanderson et al. 1986). The management of range and forest lands for multiple outputs will require a recognition of the type and quality of recreational experience desired, in combination with the production of other resources.

Minerals

Much of the western United States lies over deposits of valuable minerals, including coal and oil, metallic minerals such as lead and copper, precious metals and gems, and common building materials such as sand and gravel. Extracting these minerals is a major component of national, state and local economies. The western states of Texas, Oklahoma, California, New Mexico, Wyoming, together with Louisiana and West Virginia contributed more than 75% of the $188 billion in value added by mining in 1982 (USDA Forest Service RPA Staff in press). Future projections suggest increased domestic production of metallic minerals and increased exploration for and production of domestic energy sources (USDA Forest Service RPA Staff in press). Extensive areas in western United States have been revegetated following mining (fig. 7) and measures will have to be taken to ensure that future mineral extraction is compatible with other uses and that environmental quality is maintained (USDA Forest Service RPA Staff in press).

FOREST AND RANGELAND

Ownership

The Nation's forest and rangeland base is managed by both federal and nonfederal ownerships. Private individuals and state and local governments comprise the nonfederal ownerships, and manage 67% of the total forest and rangeland base. The remaining 33% is under federal management (Bones in press). When rangeland alone is considered, about 64% is in nonfederal ownership. For forest land, nearly 71% is in nonfederal ownership. Land ownership patterns of forest and rangeland vary by region (table 5). Large federal holdings are found in many western states and federal statutes such as the Multiple-Use Sustained Yield Act of 1960, the Wilderness Act of 1964, the National Environmental Policy Act of 1969, the Wild Free-roaming Horse and Burro Act of 1971, the Federal Land Policy and Management Act of 1976, and the National Forest Management Act of 1976 provide strong guidelines for the management of federal lands. The main emphasis resulting from this legislation is the management for multiple resources on federal lands. Private rangelands are managed by the people who own them. The management of nonfederal rangelands is affected by federal statues such as the

Figure 6.—Pack horses on rangelands (photo courtesy of Pat Aguilar, USDA Forest Service).

Figure 7.—Wheatgrass contours on reclaimed mineland in New Mexico (photo by Earl Aldon, USDA Forest Service)

"sodbuster" and "swampbuster" provisions of the Food Security Act of 1985.

Forest and Rangeland Area

Nationally, rangelands represent 34%, or 770 million acres, of the total land base of the United States (Bones in press). Forest lands occupy 32%, whereas pasture and cropland area represents 24% of the Nation's land base. The remaining 10% is classified as human-related land. Thus, over 35% of the Nation's land base has been converted from forest and rangeland for uses such as cropping, roads, industrial areas, and cities.

The present location and area of range and forest land is a function of the historical and current land use within each region of the United States (fig. 8). As the United States was first settled, large areas of eastern deciduous

Table 5.—Area (1,000 acres) of forest and rangeland in federal and nonfederal ownerships.

Region	Regional total	Forest[1]			Rangeland		
		Total	Nonfederal	Federal	Total	Nonfederal	Federal
Rocky Mountains	555,725	142,329	46,760	95,569	413,396	242,485	170,911
Pacific Coast	169,079	101,039	34,036	67,003	68,040	33,212	34,828
Southern	314,850	199,096	179,966	19,130	115,754	115,557	197
Northern	165,987	165,561	152,612	12,949	426	254	172
Alaska	291,780	119,045	101,338	17,707	172,735	102,435	70,300
U.S. total	1,497,421	727,070	514,712	212,358	770,351	493,943	276,408

[1]*Forest land includes transition land.*
Source: Darr (in press) for rangeland; Bones (in press) for forest land.

forest in the NO region were converted to cropland and then to urbanland. As of 1972, over 70% of maple-basswood and beech-maple forests within the maple-beech-birch ecosystem (fig. 2) had been converted to urban, cropland, or pasture (Klopatek et al. 1979). Large areas of productive agricultural land occur on sites formerly occupied by oak-hickory or prairie ecosystems (fig. 2) in Indiana, Illinois, and Iowa. The results of this land conversion is more land in cropland and pasture than in forest in the NO region (fig. 8). Commercial forest land, rangeland, and cropland/pasture are found in the SO region (fig. 8). These forest and range ecosystems provide much of the Nation's timber, along with hunting opportunities for white-tailed deer and wild turkey, and forage for livestock (table 4). Diverse range ecosystems still occur in the southern and western parts of the SO region (fig. 2). The eastern part of the NR region and the western parts of the NO and SO region are referred to as the Great Plains. Over 85% of the prairies dominated by bluestem grass have been converted to pasture and cropland (Klopatek et al. 1979). Agricultural economics and irrigation have fostered the conversion of the plains grassland to cropland (Huszar and Young 1984). The NR region has nearly the same acreage in cropland and pasture as in forest, however, both are overshadowed by rangeland area (fig. 8). In the western United States, the

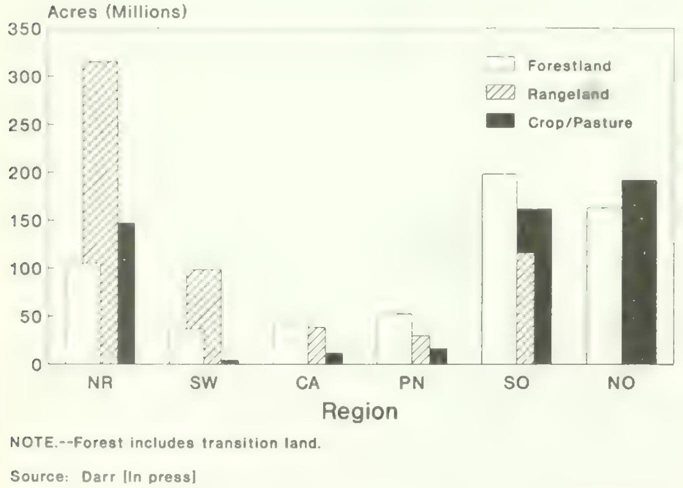


Figure 8.—Forest, rangeland, crop, and pastureland by assessment regions in the United States, 1983.

intermix of large forested areas with rangeland, along with the predominance of federal ownership, provides recreation, water, timber, grazing, and minerals management opportunities (tables 2 and 3). With few exceptions, less than 20% of the natural vegetation in these western regions have been converted to urban or other uses (Klopatek et al. 1979). Forest or rangeland acreages are dominant in the NR, the SW, and the PN (fig. 8). The PN and CA regions have large areas of forest and rangeland that provide much commercial timber, forage, and recreational use (table 3).

Because the impact of humans has had a long history in many parts of the United States, undisturbed examples of these ecosystems are managed as Research Natural Areas (RNA's) on NFS lands (Peterson and Rasmussen 1985). The principal management goals are to preserve a representative array of all significant ecosystems as sources of baseline data, to provide sites for the study of natural processes in undisturbed ecosystems, and to provide gene pool preserves for plant and animal species (Peterson and Rasmussen 1985). Because FRES ecosystems represent groupings of many vegetation types, more than one RNA exists for some forest and range ecosystems. Finer delineations of the oak-hickory ecosystem include the yellow poplar-hemlock type in Alabama and the post oak-black oak type in Ohio (table 6). The broad geographic range of the lodgepole pine ecosystem is represented by RNA's in Oregon, Montana, and Wyoming (table 7). The diversity of wet grassland ecosystems is protected in eastern states such as Delaware, southern states such as Florida and Texas, and western states such as Montana and New Mexico (table 8). While many National Forests have RNA's, some ecosystems are found only on other ownerships, for example the shinnery ecosystem on BLM-administered lands in New Mexico.

The conservation of habitat is the most cost-efficient manner to protect large numbers of plant and animal species and associated ecological processes. This conservation includes, not only the ecological reserves such as Forest Service RNA's, but also management strategies to protect and restore nonreserve habitat (Conservation Foundation 1987). In the United States, some form of protection exist on nearly 7.2% of the land (Conservation Foundation 1987). This estimate includes federal areas such as RNA's as well as state and private reserves (Juday 1988).

Table 6.—Research natural areas in eastern forest ecosystems on federal lands.[1]

FRES type	SAF type	National forest and state
White-red-jack pine	Eastern hemlock	Allegheny, Pennsylvania
		Upper Peninsula EF, Michigan
		George Washington, Virginia
	Red pine	Chippewa, Minnesota
	Eastern white pine	Superior, Minnesota
	Hemlock-yellow birch	Hiawatha, Michigan
Spruce-fir	Red spruce	White Mtn., New Hampshire
	Balsam fir	Superior, Minnesota
Loblolly-shortleaf	Shortleaf pine	Daniel Boone, Kentucky
Oak-pine	Loblolly pine-hardwood	Mississippi, Mississippi
Oak-hickory	Yellow poplar-hemlock	William Bankhead, Alabama
	White-black-northern red oak	Talladega, Alabama
		Ouachita, Arkansas
		Pisgah, North Carolina
	Post oak-black oak	Wayne Hoosier, Ohio
	Chestnut oak	George Washington, Virginia
	Northern red oak	Chequamegon, Wisconsin
Oak-gum-cypress	Sweet bay-swamp tupelo -red maple	Osceola, Florida
	Overcup oak-water hickory	Mississippi, Mississippi
	Baldcypress-water tupelo	Kisatchie, Louisiana
	Sweetgum-willow oak	Francis Marion, S. Carolina
	Water-swamp tupelo	Francis Marion, S. Carolina
Elm-ash-cottonwood	Sugarberry-American elm -green ash	Mississippi, Mississippi
Maple-beech-birch	Sugar maple	Upper Peninsular EF, Michigan
		McCormick EF, Michigan
		Superior, Minnesota
	Beech-sugar maple	Wayne Hoosier, Indiana
	Sugar maple-beech-yellow birch	Pisgah, North Carolina
Aspen-birch	Paper birch	Chippewa, Minnesota

[1] *The Society of American Foresters (SAF) type with the most acres was used to classify the RNA. EF is experimental forest located on a national forest.*

Sources: Franklin et al. (1972a, 1972b); National Science Foundation, Federal Committee on Ecological Reserves (1977); Peterson and Rasmussen (1985); Shanklin (1960).

Land Grazed by Wild and Domestic Herbivores

Grazing is a natural process in most ecosystems. Before European settlement, North American ecosystems were grazed by large numbers of wild herbivores, such as antelope, bison, deer, and elk. Climax vegetation evolved with a complex set of relations between plants, animals, and fire. Since settlement, wild grazers and browsers have declined concurrent with the rise of domestic grazers and browsers (Joyce and Skold 1988, Wagner 1978). Early settlers and those who followed were a new ecological force that realigned the grazing influences already present. Wild grazers were replaced by increasing numbers of domestic grazers, and wild browsers by domestic browsers (Stoddart et al. 1975). Recognized as one of the important resources of rangelands, wildlife and their habitats have increased through recent multiple-use management (Committee on Impacts of Emerging Agricultural Trends on Fish and Wildlife Habitat 1982).

Assessing the land currently grazed by wild and domestic herbivores is a complicated process, hindered by the lack of appropriate data. Not all rangeland or forest land is grazed by large herbivores. Steep slopes, rocky outcrops, highly erosive sites, and flooded areas are unsuitable for grazing. Livestock grazing is prohibited on some ecological preserves and areas under special management. Islands of forest or rangeland may be surrounded by inhospitable environments, making their grazing use by wildlife inaccessible. The widespread distribution of large herbivores across the United States indicates a similar wide distribution of grazinglands (figs. 4 and 8). National statistics for the area grazed by livestock are available for forest and pasture on nonfederal lands and some federal lands. These statistics provide a lower limit of the amount of land grazed by large herbivores.

Nationally, over 16%, or 74.7 million acres, of nonfederal forest land was grazed by livestock in 1982. The percentage of nonfederal forest land grazed in western

Table 7.—Research natural areas in western forest ecosystems on federal lands.[1]

FRES type	SAF type	National forest and state
Douglas-fir	Interior Douglas-fir	Pike, Colorado
		Boise, Idaho
		Salmon, Idaho
		Coconino, Arizona
		Lolo, Montana
	Douglas-fir—hemlock	Willamette, Oregon
		Mount Hood, Oregon
		Mount Baker, Washington
		Gifford Pinchot, Washington
	Port Orford-cedar	Siskiyou, Oregon
Ponderosa pine	Interior ponderosa pine	San Juan, Colorado
		Black Hills, South Dakota
		Santa Fe, New Mexico
		Coconino, Arizona
		Wenatchee, Washington
		Winema, Oregon
		Malheur, Oregon
		Deschutes, Oregon
		Coronado, Arizona
		Fort Valley EF, Arizona
		Ochoco, Oregon
		Lassen, California
		Shasta Trinity, California
		Boise, Idaho
		Custer, Montana
	Ponderosa—sugar pine-Douglas-fir	Rogue River, Oregon
	Pacific ponderosa pine-Douglas-fir	Rogue River, Oregon
	Jeffrey pine	Inyo, California
	Western juniper	Modoc, California
	Arizona cypress	Coconino, Arizona
		Coronado, Arizona
Western white pine	Western white pine	Kaniksu, Idaho
		Flathead, Montana
Fir-spruce	Blue spruce	Uncompahgre, Colorado
	Engelmann spruce-subalpine fir	Gunnison, Colorado
		Pike, Colorado
		Medicine Bow, Wyoming
		Cococino, Arizona
		Colville, Washington
		Willamette, Oregon
		Kaniksu, Idaho
		Manti-Lasal, Utah
	Bristlecone pine	Arapaho, Colorado
	Mountain hemlock	Gifford Pinchot, Washington
		Williamette, Oregon
	Grand fir	Mount Hood, Oregon
		Umatilla, Washington
Hemlock-Sitka spruce	Western hemlock	Tongass, Alaska
		Mount Baker, Washington
		Siuslaw, Oregon
		Olympic, Washington
	Hemlock-Sitka spruce	Tongass, Alaska
		Siuslaw, Oregon
	Western red cedar	St. Joe, Idaho
	Coastal true fir-hemlock	Mount Hood, Oregon
		Mount Rainier, Washington
		Gifford Pinchot, Washington
		Williamette, Oregon
	Western red cedar-western hemlock	Mount Baker, Washington
		Tongass, Alaska

Table 7.—Continued

FRES type	SAF type	National forest and state
Larch	Larch—Douglas-fir	Coer D'Alene, Idaho Lolo, Montana
Lodgepole pine	Lodgepole pine	Bighorn, Wyoming Wallowa-Whitman, Oregon Beaverhead, Montana
Redwood	Redwood	Siskiyou, Oregon Redwood EF, California
Western hardwoods	Oak-diggerpine	San Joaquin Experiment Range, California
	Aspen	Apache, Arizona Caribou, Idaho Wasatch, Utah
	Canyon live oak	Angeles, California
	Cottonwood-willow	Wasatch, Utah
	Interior live oak	Coronado, Arizona

[1]*The Society of American Foresters (SAF) type with the most acres was used to classify the RNA. EF is experimental forest located on a national forest.*

Sources: Franklin et al. (1972a, 1972b); National Science Foundation, Federal Committee on Ecological Reserves (1977); Peterson and Rasmussen (1985); Shanklin (1960).

regions, 72% RM and 33% PC, was much higher than in the NO (6%) and SO (13%) regions (USDA Soil Conservation Service 1987a). The limited amount of nonfederal forest land in the western regions tends to focus resource use on these lands. Much of the forest land in the SO region is used to produce timber and commonly is not managed for grazing, although opportunities for grazing livestock as a silvicultural tool are receiving closer examination (Doescher et al. 1987, Krueger 1987, Pearson 1987). The importance of pasture as a roughage source is evidenced by the extent of grazed pastures. More than 74% of all pasture in the United States was grazed in 1982 (USDA Soil Conservation Service 1987a). No estimates of the percentage of rangeland grazed were available for nonfederal land.

Not all land within the NFS allotments can be grazed. Only 49.6 million acres out of 99.8 million acres are suitable for grazing (USDA Forest Service 1988c). Suitable acres are those acres that can be grazed without sustaining damage to the range resource. Additional acres outside of NFS allotments are suitable for grazing, but no inventory estimates of these acres are available.

No estimate of suitable lands on BLM-administered lands is available. Thus, for this assessment, the acreage estimate for grazed BLM-administered lands incorporates all acres within BLM allotments, over 171 million acres (tables 13 and 14 in USDI Bureau of Land Management 1987). An additional 51 million acres are grazed by livestock on other federal, state, and local agency lands in the western regions, providing over 7.1 million AUMs (Bartlett et al. 1983).

Unfortunately, the available information is insufficient to precisely determine acres grazed by large herbivores in the United States. No acreage information is available to estimate wild herbivore grazing nationally, or livestock grazing on rangelands. If it is assumed that all nonfederal rangeland is grazed, and the above acreage estimates represent the minimum federal land grazed, then over 841 million acres of forest and rangeland are grazed by livestock. This represents 70% of the forest and rangeland base, or 44% of the total land base (excluding Alaska). Cropland and pasture provide a significant amount of forage also but are not included here.

RANGE VEGETATION

Vegetation on range and forest land is a function of climate, fauna, and soils. The management of vegetation affects the total production and composition of plant species which in turn affects the mix of range outputs. The vegetation within some forest and range ecosystems has been altered by overgrazing, disruption of the natural fire cycle, invasion of exotic plant or animal species, alteration of the flow regime from the diversion of water, disturbance from mining, and recreational use.

Range Condition and Ecological Status

Traditionally, the term "range condition" has been used as a measure of the health of the range ecosystem. Range condition has been defined as the extent of departure from the climax vegetation of a site (Stoddart et al. 1975). Early measurements involved a comparison of species present with species of the climax community. A large departure implied poor condition. This rating was based on the susceptibility of the plant species to grazing, and by this definition, a direct cause and effect relation was assumed between livestock overgrazing and the status of vegetation in a deteriorated range. The concept of range condition was difficult to apply to forested

Table 8.—Research natural areas in range ecosystems on federal lands.[1]

Ecosystem	National forest and state
Sagebrush	Snoqualmie, Washington Beaverhead, Montana
Desert shrub	Gila, New Mexico Tonto, Arizona Desert Experiment Range, Utah
Shinnery	Roswell District, BLM, New Mexico
Texas savanna	Laquna Atascosa NWR, Texas
Southwestern shrubsteppe	Bosque del Apache NWR, New Mexico
Chapparral-mountain shrub	Okanogan, Washington Mendocino, California Sierra, California
Pinyon-juniper	Inyo, California Toiyabe, Nevada
Mountain grasslands	Umatilla, Washington
Mountain meadows	Gifford Pinchot, Washington
Plains grasslands	Commache Grasslands, Colorado Custer, North Dakota
Prairie	Nebraska, Nebraska
Desert grasslands	Coronado, Arizona
Wet grasslands	Bombay Hook NWR, Delaware Loxahatchee NWR, Florida Brazoria NWR, Texas Bosque del Apache NWR, New Mexico Lolo, Montana
Annual grasslands	San Joaquin Experiment Range, California
Alpine	Inyo, California

[1] *The type with the most acres was used to classify the RNA. SAF types were not available for range ecosystems. When no RNAs existed for an ecosystem on National Forest System lands, sites managed by other federal agencies were given. NWR is National Wildlife Refuge administered by USDI Fish and Wildlife Service. BLM is Bureau of Land Management.*

Sources: Franklin et al. (1972a, 1972b); National Science Foundation, Federal Committee on Ecological Reserves (1977); Peterson and Rasmussen (1985); Shanklin (1960).

ecosystems, and did not address the impacts on vegetation of other uses of rangeland and forest ecosystems. In addition, the Range Inventory Standardization Committee (1983) pointed out that most vegetation and its physical environment has been disturbed by past use such that the potential natural community (PNC) of the site differs from the original pristine climax plant community.

Two concepts are important in the assessment of forest and rangelands: (1) the maintenance of the long-term productive potential of the site; and (2) the present level of production relative to the potential for a specific use, such as livestock grazing or wildlife habitat (Range Inventory Standardization Committee 1983). The Range Inventory Standardization Committee proposed that ecological status, and a resource value rating be used to assess these two concepts. Ecological status is use-independent whereas a resource value rating is the value of the vegetation for a particular use, such as wildlife habitat or domestic grazing.

Ecological status is a measure of the successional stage of the site. Natural disturbances, such as drought, wild fires, grazing by native fauna, and insects are a natural part of the development of any plant community. Once disturbed and if left without further perturbation, the plant community undergoes a change in function and structure to develop a climax community or PNC (Range Inventory Standardization Committee 1983). The stages of the successional path are referred to as early seral, midseral, late seral, and PNC. The resource outputs vary with each stage, thus management decisions may favor one stage over another, because some successional stages are more productive with respect to the desired resource outputs. The difference between climax, as traditionally used, and PNC reflects the conditions existing today where much of the Nation's vegetation has been altered by past use, including species introductions, grazing, cropping, or logging. On some sites, the PNC will be very different from the climax vegetation type (Range Inventory Standardization Committee 1983).

Because the use of ecological status and resource value ratings represent a departure from the traditional inventory measurements, a time lag will exist before resource inventories may incorporate this approach to measuring range vegetation. Therefore, the current status of range condition must be discussed in light of the definitions used in the existing inventories from different federal agencies.

The Soil Conservation Service (SCS) inventories nonfederal rangelands, and defines range condition as:

> . . .the present state of vegetation of a range site in relation to the climax (natural potential) plant community for that site. It is a expression of the relative degree to which the kinds, proportions, and amounts of plants in a plant community resemble that of the climax plant community for the site (USDA Soil Conservation Service 1976).

The BLM has used different definitions of range condition (Box et al. 1976), but in 1984, BLM reported that future condition estimates would be based on the definitions of ecological status and resource value ratings given above (USDI Bureau of Land Management 1984). Thus, the 1986 figures for range condition reflect ecological site inventory data on about 52% of the BLM-administered lands, plus range condition estimates based on earlier inventories and professional judgment on the remaining lands. The BLM describes range condition on their lands as similarity with the PNC: excellent = 76-100% similarity, good = 51-75%, fair = 26-50%, and poor = 0-25% (USDI Bureau of Land Management 1987).

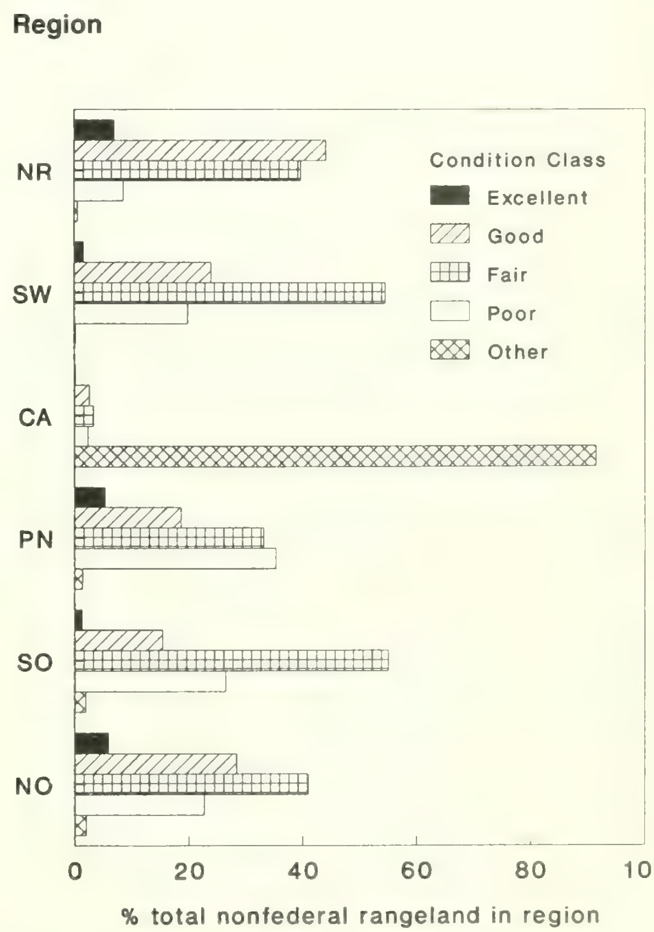
The FS uses ecological status to describe rangeland and forest ecosystems on NFS lands (USDA Forest Service Service Range Management Staff 1986). Ecological status is rated by one of the following categories: PNC, late-seral, midseral, and early-seral stages. These categories are not equivalent to the range condition categories of excellent, good, fair, and poor. Ecological status relates the vegetation to the potential vegetation, not the usefulness of the vegetation to a particular use such as grazing. The usefulness of the vegetation for grazing is assessed by the resource value rating for livestock forage. A satisfactory livestock forage rating is defined as follows: adequate protection for soil, acceptable levels of forage species composition and production or acceptable trend in composition and production for the intended use.

Range condition establishes the current status of the vegetation, and the term "trend" has been used to assess the direction of change of the current community with respect to PNC. Again, these definitions vary by resource inventory. The SCS defines trend as the direction of change in range condition, and measures apparent trend through species composition changes, abundance of seedlings and young plants, plant residues, plant vigor, and the condition of the soil surface (USDA Soil Conservation Service 1976). The FS defines trend in relation to direction of change in ecological status, that is movement toward, away from, or no change with respect to PNC.

Condition of Nonfederal Rangelands

As reported by USDA Soil Conservation Service (1987c), range condition as a percentage of the total nonfederal rangeland base (excluding Alaska) in 1982 was as follows: excellent, 4%; good, 31%; fair, 47%; and poor, 17%. In figure 9, the Other category reflects lands for which range condition ratings have not been assigned such as the annual grasslands of California and areas elsewhere seeded to and dominated by introduced species (USDA Soil Conservation Service 1987c).

The SCS reported that at the national level, the trend in condition of rangelands in the private sector was static on 69% of the land, up on 16%, and down on 15%. The SCS Second Appraisal suggested that, although inventory methods differ considerably, the last three SCS range assessments (1963, 1977, and 1982) indicated that the condition of nonfederal range is improving (USDA Soil Conservation Service 1987c).



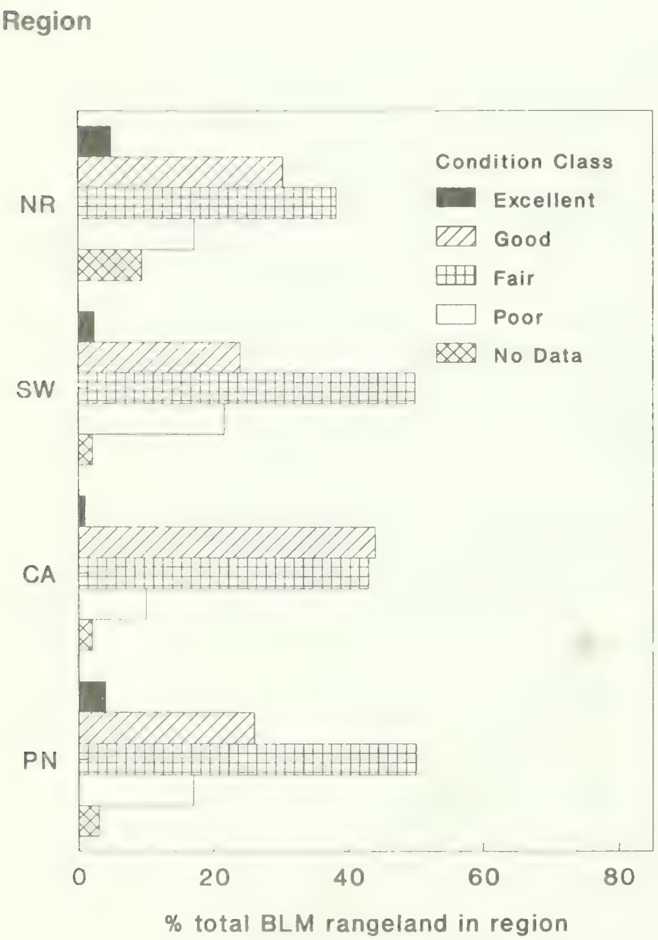
Source: USDA, Soil Conservation Service (1987c)

Figure 9.—Range condition on nonfederal rangelands by assessment regions in the United States.

Condition of Bureau of Land Management-Administered Lands

In 1986, the condition of BLM-administered rangelands at the national level in terms of percentage of total rangeland was: excellent, 4%; good, 30%; fair, 41%; and poor, 18%. These numbers do not include 7% of BLM-administered lands which were unsuitable for grazing or for which data or estimates of condition were unavailable (table 16 in USDI Bureau of Land Management 1987). Alaska was also not included. Condition on BLM-administered lands by assessment regions is shown in figure 10.

Trend information on BLM-administered lands was not available, however data from a number of historical reports were reviewed and compiled into similar categories by Box et al. (1976) and Box (1988). Although these data suggest that condition is improving, Box et al. (1976) stressed that different techniques were used and comparisons are difficult to make. Better inventory data would be valuable (Box 1979).



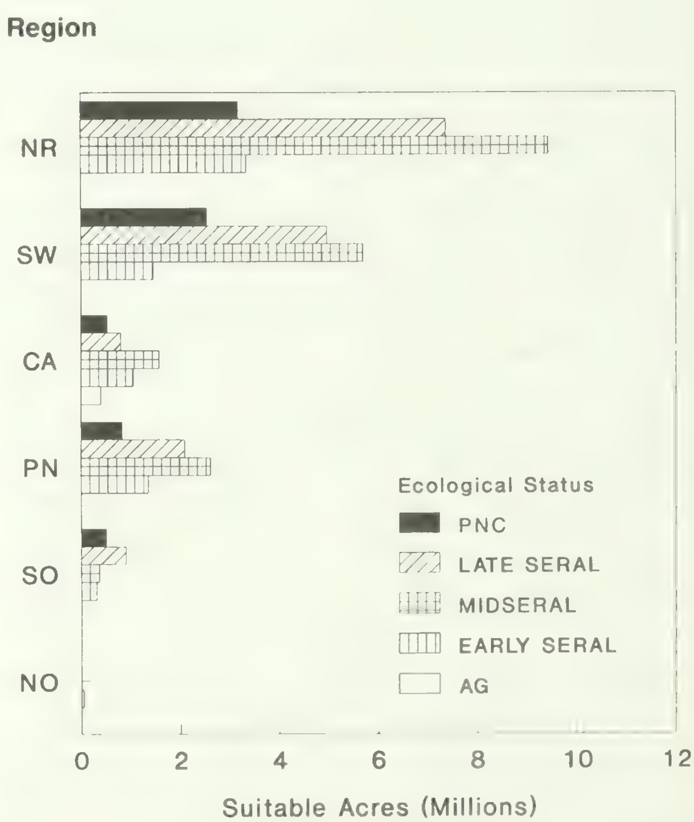
Source: USDI, Bureau of Land Management (1987)

Figure 10.—Range condition on Bureau of Land Management-administered land by assessment regions in the United States.

Condition of National Forest System Lands

A summary of the ecological status of NFS lands nationally indicates that 15% of all NFS lands are at PNC, 31% in late-seral, 38% in midseral, and 15% in early-seral. These numbers do not include annual grasslands (0.8%). The regional distribution of ecological stages varies (fig. 11). The western and southern regions have large amounts of forest land. Timber harvesting and clearcutting place the site in an earlier successional stage, allowing for increased production of herbaceous and shrubby species. Regions with less commercial timber, more grass and shrubland, and a history of grazing tend to have a clumped distribution of acres in the midseral or late-seral stages (fig. 11).

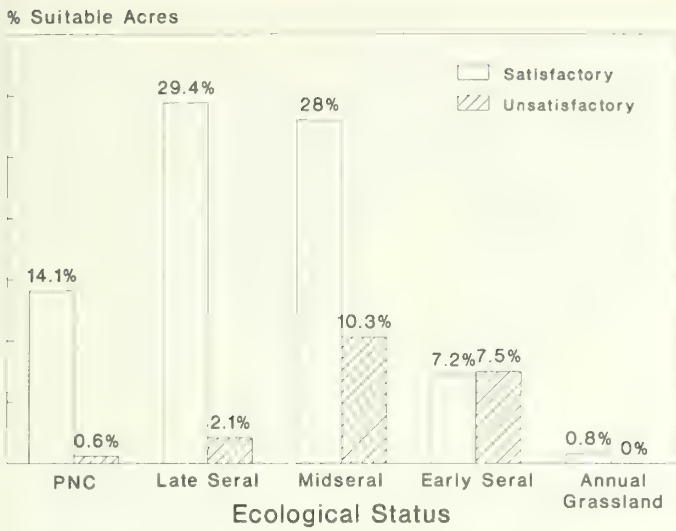
With respect to livestock management, the resource value rating of NFS lands at the national level indicates that 80% are in satisfactory management and 20% are in unsatisfactory management. The early-seral and midseral stages have more lands in unsatisfactory management (fig. 12). In some forest types, early-seral and midseral stages have a more productive herbaceous understory than late-seral or PNC, and thus, these stages would be grazed more often.



NOTE.— AG = annual grasslands.

Source: USDA, Forest Service (1986b)

Figure 11.—Ecological status for National Forest System lands by assessment regions in the United States.

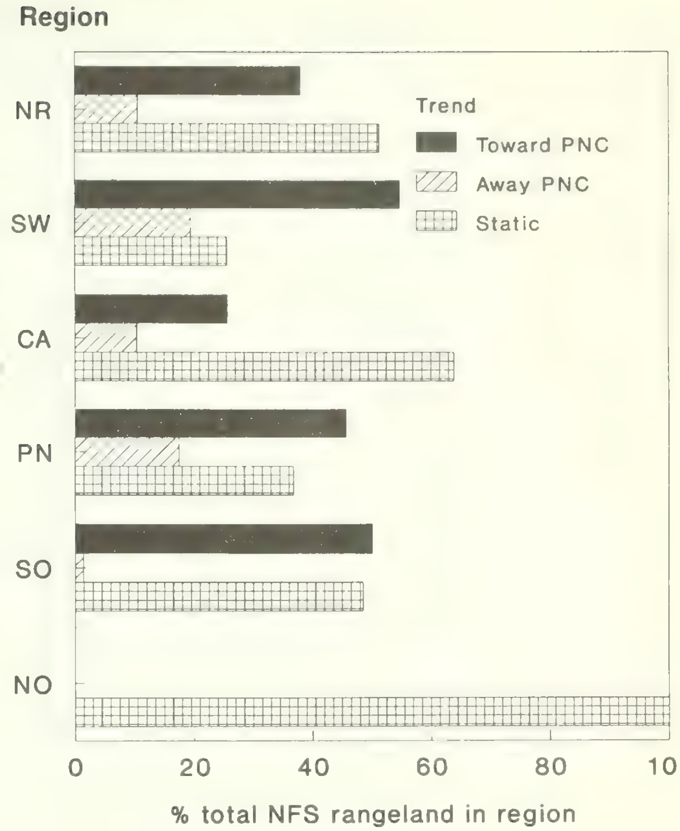


Satisfactory • lands with adequate soil protection, forage species composition and production, and acceptable trend in forage species

Source: USDA, Forest Service (1986b)

Figure 12.—Livestock forage value rating within ecological status on National Forest System lands.

At the national level, 43% of NFS lands have a static trend in ecological status, 14% are moving away from PNC and 43% are moving toward PNC. The regional numbers follow the national trend; most of the acres are either moving toward PNC or are static (fig. 13). The SW region has the greatest percentage of acres moving away from PNC, a reflection of 400 years of grazing, and severe overgrazing at the turn of the century. Substantial improvements have been made in this region, as indicated by the large percentage of acres moving toward PNC.



Source: USDA, Forest Service (1986b)

Figure 13.—Trend in ecological status on National Forest System lands by assessment regions in the United States.

Forage Available for Livestock Grazing

The national production of forage is difficult to quantify. As discussed in detail in Chapter 2, forage production is a function of the available land, productivity, and the management of that land. As management can significantly affect the quantity produced, and the implementation of range technology has not been nationally inventoried, a determination of the production of forage is difficult. As reliable livestock inventories are available, however, forage consumed by livestock can be estimated and interpreted as a lower estimate of the forage produced on rangelands and forest lands. The permitted and leased grazing on public lands provides an additional estimate of the supply of forage from these lands.

Permitted or Leased Range Forage

The NFS permitted 10.1 million Animal Unit Months (AUMs) to be grazed in 1985 and 1986 (USDA Forest Service 1986b, 1987b). The RM Region supplied most of these AUMs (table 9). The BLM permitted 13.5 and 12.5 million AUMs[3] to graze in 1985 and 1986, respectively (USDI Bureau of Land Management 1986, 1987). The RM region supplied the majority of these AUMs also (table 9). Comparisons with the AUMs reported from other federal, state, and local agencies (Bartlett et al. 1983) indicate that the NFS and the BLM are the predominate suppliers of forage in the public sector. These other public ownerships supplied slightly more than 7 million AUMs.

Consumption of Grazed Forages in Livestock Production

Beef cattle and sheep represent the largest inventories of livestock that use grazed roughages in the United States. Dairy cattle, goats, horses, and hogs use grazed forages, but their consumption is less than 5% of the total forage consumed annually. Although actual feed consumption figures are not available, USDA estimated that less than 1% of the feed costs for dairy cows is used for pasture (Gee and Madsen 1988). The 1.5 million goats consume about 3.6 million AUMs of grazed forages (Gee

[3]*Animal unit months (AUMs) are defined differently by FS and the BLM. For this report, an animal unit month (AUM) is the forage required to sustain one animal unit for 1 month where one animal unit is considered to be one mature cow or equivalent. For this report, the FS's definition of AUMs was used and BLM AUMS were converted to a unit that is similar to FS AUMs by multiplying the BLM Animal Months (AMs) by 1.2 (USDA Forest Service and USDI Bureau of Land Management 1986).*

Table 9.—Number of permitted AUMs on public lands by region, 1985, 1986.

Region	Forest Service	Bureau of Land Management[1]	Total
1985			
Northern Rocky	5,928,000	8,938,800	14,866,800
Southwest	2,504,000	2,715,600	5,219,600
Rocky Mountains	8,432,000	11,654,400	20,086,400
California	621,000	464,400	1,085,400
Pacific North	745,000	1,222,800	1,967,800
Pacific Coast	1,366,000	1,687,200	3,053,200
Southern	248,000	-------[2]	248,000
Northern	79,000	-------[2]	79,000
Total	10,125,000	13,341,600	23,466,600
1986			
Northern Rocky	5,906,000	8,263,200	14,169,200
Southwest	2,510,000	2,656,800	5,166,800
Rocky Mountains	8,416,000	10,920,000	19,336,000
California	592,000	493,200	1,085,200
Pacific North	748,000	1,122,000	1,870,000
Pacific Coast	1,340,000	1,615,200	2,955,200
Southern	239,000	-------[2]	239,000
Northern	78,000	-------[2]	78,000
Total	10,073,000	12,535,200	22,608,200

[1] *Bureau of Land Management AUMs were converted to a unit that is similar to Forest Service AUMs by multiplying by 1.2 (after USDA Forest Service, and USDI Bureau of Land Management (1986)).*
[2] *No land managed for grazing by BLM in this region.*
Source: USDA Forest Service (1986b, 1987b); USDI Bureau of Land Management (1986, 1987).

and Madsen 1988). This number is small in comparison with the total AUMs consumed by beef cattle and sheep. Although hogs use some grazed roughages, USDA estimated that less than 1% of hog feed costs are for pasture (Gee and Madsen 1988). The estimated 2.0 million horses (fig. 4) also represent a small demand for grazed roughages relative to beef cattle and sheep. Although recreational horses outnumber work horses, the grazed roughages demand from recreational stock is minor as hay and concentrate comprise most of their feed mix (Smith et al. 1986).

Grazed forages consumed by beef cattle and sheep include deeded nonirrigated rangeland and pasture, publicly owned grazing land, deeded irrigated pasture, and crop residues. National estimates of forage consumption by beef cattle and sheep (table 10) are derived from USDA Economic Research Service livestock enterprise budgets (Gee et al. 1986a, 1986b). The structure of these budgets is based on the 1981 national survey conducted by the USDA Statistical Reporting Service in which detailed estimates were made of feed consumption by type of feed and season of use. Nationally, beef cattle consume about 96% of the estimated total grazed forages (table 10). In 1985, total grazed forages for beef cattle were supplied primarily by the private sector; 87% came from deeded nonirrigated grazing land, 6% from public land, 5% from crop residues, and 2% from irrigated pasture. In contrast to this distribution, the supply of grazed forages for sheep was predominately from deeded grazing land (60%) and public land (28%). Consumption of grazed forages in livestock production is examined in detail in Chapters 2 and 3.

INTERNATIONAL RANGE RESOURCE

Rangeland and pasture comprise a major portion of the land base in many of the world's countries (fig. 14). For Africa, Asia, and Oceania, rangeland and permanent pasture is the dominant land cover (Food and Agriculture Organization 1986). The use of these lands is determined by the ecology and economy along with the customs and traditions of individual countries. If the lands are grazed, cultural traditions also influence the type and mix of domestic animals (Rourke 1986, 1987). Livestock numbers are greatest in Asia, a reflection of its large land mass, extensive area of permanent pasture, and additional forage available from cultivated cropland (fig. 15). Africa, with the largest amount of land in permanent pasture of all the world's regions, is second only to Asia in the number of sheep, goats, buffaloes, and camels (Food and Agriculture Organization 1986).

Use of the range resource in the United States is affected by the global use of land, and in particular, the global range resource. The United States interaction with global rangelands occurs through the market place, political systems, and education. As discussed in more detail

Table 10.—Grazed forage consumption (1,000 AUMs and percentage of total) by beef cattle and sheep in the United States, 1985.

Source of grazed forage	Cattle		Sheep		Total	
Deeded Land						
Non-irrigated	359,359	(87.2)	10,742	(56.3)	370,101	(85.8)
Irrigated	8,557	(2.1)	725	(3.8)	9,283	(2.2)
Public land	24,163	(5.9)	5,304	(27.8)	29,467	(6.8)
Crop residue	20,011	(4.8)	2,302	(12.1)	22,312	(5.2)
Total	412,090		19,073		431,163	

Source: Gee and Madsen (1988).

in Chapter 3, about 8% of the meat consumed in the United States is imported, and 1.5% of the meat produced in the United States is exported (USDA Economic Research Service 1986). Through our political system about $0.9 billion of U.S. foreign aid is allocated for food aid, and over $6 billion for development assistance which includes food loans and grants, and technical assistance projects (Meiman 1988). Although credit for increasing self-sufficiency in food production has been given to university outreach programs and the Green Revolution (Meiman 1988), recent range and livestock programs have been poorly evaluated (Thomas 1987). One reason for poor success has been the inability of development programs to recognize local cultural and ecological systems which may be very different from western traditions and temperate ecosystems (Ellis and Swift 1988). Future development projects will need to understand the cultural and ecological systems before establishing projects.

The Food and Agriculture Organization (1977) concluded that available world food supplies should be sufficient to provide everyone with an adequate diet if the problem of distribution could be solved. In The Global 2000 Report to the President, projections for food and agriculture suggested a continuation in the growing importance of variability in supply (Council of Environmental Quality and USDS 1980). Expansion of agriculture into marginal areas increases the susceptibility of crop production to weather fluctuations, and in the future a larger proportion of the world's food supplies will be dependent on *favorable* (above average) rather than average rainfall and temperature (Council on Environmental Quality and USDS 1980).

The results of a recent United Nations report indicate that desertification is extending in area and intensity world-wide (fig. 16) (UNEP 1984). As of 1984, 35% of the earth's land surface and 20% of the earth's human population were considered to be threatened by encroaching deserts (Marbutt 1984). At least 35% of this total land surface has lost more than 25% of its productivity and is in serious need of reclamation (Karrar 1984, Marbutt 1984).

Over 7,600 million acres is at least moderately desertified and half of the world's rangeland is in severe or very severe desert conditions (Marbutt 1984). The proportion is higher (>60%) in developing regions, and

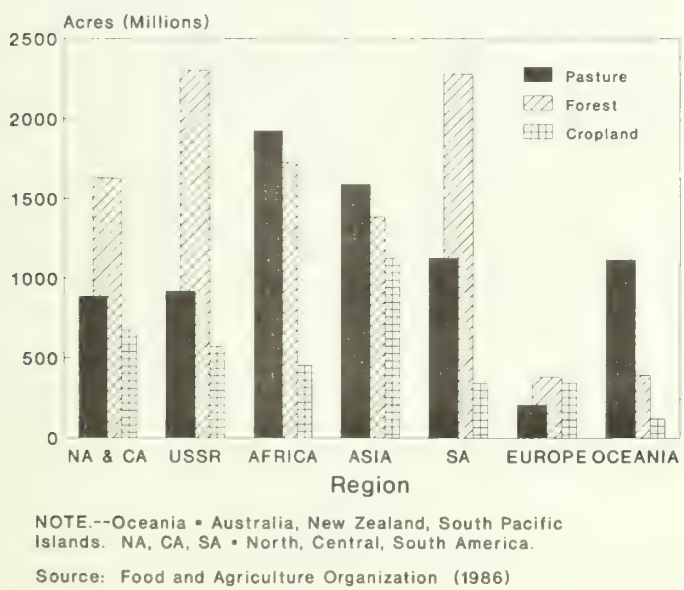


Figure 14.—Forest, permanent pasture (tame, native, and rangeland), and cropland area of the world, 1984.

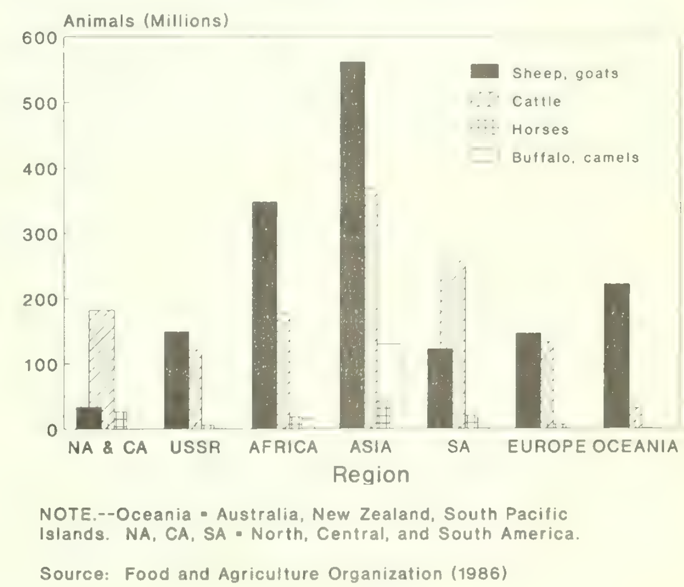


Figure 15.—Number of sheep, goats, cattle, horses, buffalo, and camels in 1985 by major regions of the world.

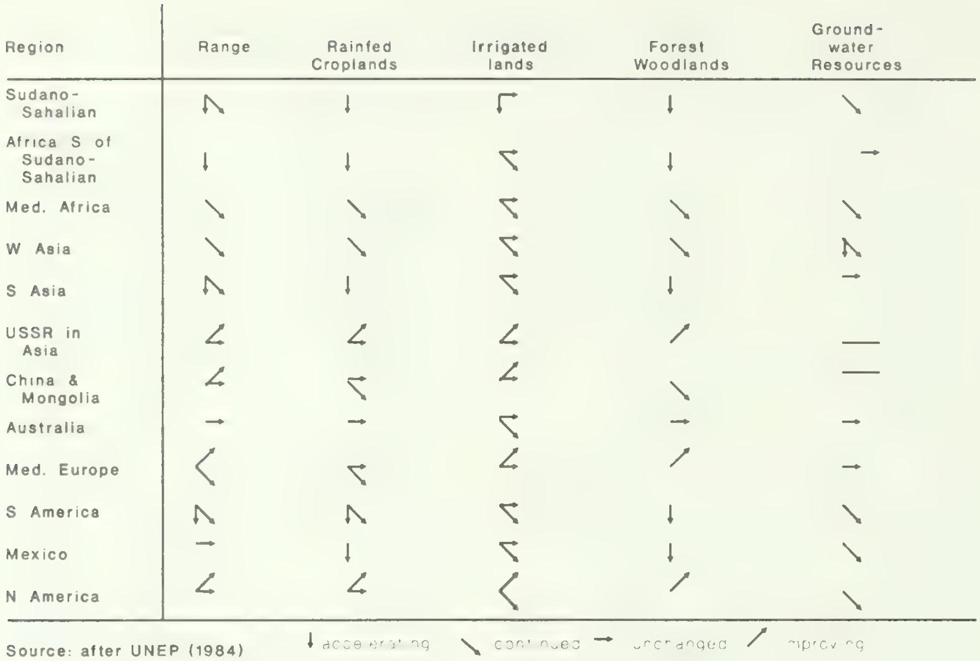


Figure 16.—Regional trends of desertification within land-use and major natural resources.

lower (<40%) in the developed regions such as North America and Australia. Rangeland areas of immediate concern are the interfaces between the semi-arid grazinglands and the densely-populated rain-fed croplands. Agriculture is encroaching upon grazinglands, restricting livestock and wildlife to smaller areas. Other areas of concern are the interfaces between semi-arid and subhumid mixed farming areas in hilly tracts, as in Africa south of the Sudano-Sahelian region and in Andean South America. In developed regions, the invasion of woody vegetation of low pastoral value was considered to be the major problem of rangelands (Marbutt 1984). Increased population growth coupled with increasing poverty in many countries has and will continue to put pressure on range vegetation and plant species survival (Lucas and Synge 1981). This pressure comes at a time when research on new or alternative agricultural and industrial crops has increasingly turned to the vast unstudied plant resources of the tropical zones (Plotkin 1988).

SUMMARY

Range and range resources mean many things to many people. Range vegetation is defined as grasses, grass-like plants, forbs, and shrubs. When the plant community is dominated by this type of vegetation, the land is referred to as rangeland. Although rangelands predominate in western United States as natural grasslands, shrublands, savannas, deserts, tundra, alpine, coastal marshes, and wet meadows, rangelands in the eastern United States occur as tallgrass prairie, marshes, or wet meadows. Riparian ecosystems and plant communities dominated by introduced species are also considered rangeland. About 34% or 770 million acres of the total land base in the United States is rangeland.

Range vegetation is the building block for multiple resource outputs from rangelands and forests. Range outputs include native plants for agricultural, reclamation, or landscaping purposes; forage for wild and domestic herbivores; habitats for wildlife, threatened and endangered plants and animals, and wild horses and burros; water; recreation; and minerals.

Range condition is reported by various federal agencies, and in light of the different definitions used in the current inventories, range condition is discussed for each reporting agency. The SCS reported condition as a percentage of the total nonfederal rangeland base in 1982: excellent, 4%; good, 31%; fair, 47%; and poor, 17%. The BLM reported 1986 figures as follows: excellent, 4%; good, 30%; fair, 41%; and poor, 18%. On NFS land, ecological status was reported as follows: 15% at PNC, 31% in late-seral, 38% in mid-seral, and 15% in early-seral. At the national level, 80% of NFS lands are in satisfactory management for livestock.

Forage consumed by livestock can be interpreted as a lower estimate of the forage produced on rangelands and forest lands. The NFS permitted 10.1 million AUMs to be grazed in 1985 and in 1986. The BLM permitted 13.5 and 12.5 million AUMs to be grazed in 1985 and 1986. Other public ownerships supplied less than 8 million AUMs.

Beef cattle and sheep represent the largest inventories of livestock that use grazed roughages in the United States. Dairy cattle, goats, horses, and hogs use grazed forage but their consumption is less than 5% of the total forage consumed annually. Nationally, beef cattle consume 431 million AUMs; 86% comes from deeded nonirrigated grazing land, 7% from public land, 5% from crop residues, and 2% from irrigated pasture. The supply of grazed forage for sheep was different than for cattle in that only 60% came from deeded grazing land and 26% from public land.

CHAPTER 2: FACTORS AFFECTING FORAGE PRODUCTION

INTRODUCTION

Production of Range Resource Outputs

Natural resource outputs, such as timber, forage for wild and domestic herbivores, water, and recreation are produced jointly from forest and rangeland ecosystems. Different management goals yield different mixes of these outputs. The national supply of these resources is a function of efforts in individual enterprises and on public lands. The future supply of these resource outputs is closely associated with their future demand. The future management of forest and rangelands in private and public ownerships will determine the future supply of these outputs.

Quantifying the future supply of these range resource outputs at the national level involves an analysis of factors underlying their production. The future national supply of outputs, such as native plants for harvest or cultivation, is difficult to quantify because the factors affecting demand or supply are local. The future supply of wildlife, wild horses and burros, and livestock is dependent on the future supply of forage. Range vegetation is fundamental in the joint production of many range outputs, including forage. This chapter focuses on quantifying the future supply of forage as a function of rangeland productivity and land availability for grazing. As many factors associated with forage demand influence production, future supply is closely related to future demand. Factors underlying supply (this chapter) and underlying demand (Chapter 3) are used to determine the future forage supply and demand at the national level (Chapter 4). A case study projecting the impact of resource management and land use changes on forage production at the regional level is presented (this chapter) as a potential method to analyze resource interactions in assessments.

Determinants of Forage Supply

Forage, that part of vegetation that is available for consumption by herbivores, is produced on forest land, rangeland, pasture, hayland, cropland (after crop harvest), and cropland used for pasture. Forage is produced on private and public lands. Range vegetation covers the landscape naturally, and range management influences the quality and quantity of the forage component of range vegetation. Forage on forest and rangelands is typically produced with little or no agronomic practices, whereas forage on pasture or haylands may be intensively cultivated, seeded with improved species, irrigated, and fertilized. Where economically feasible, such management practices may be used to enhance forage production on forest and rangelands. Mechanically harvested forages from pasture or haylands are important in providing feed when grazed forages are unavailable.

The production of forage is undertaken with the expectation of some value accruing from the production effort (Tyner and Purcell 1985). Forage is used to produce livestock for meat and other products, wild horses and burros for preservation, and wildlife for recreation or preservation. The value attached to forage differs depending on the output, and the quantity of forage produced depends on the value of the output to the producer. Within a farm or ranch enterprise, forage production will be determined by the demand for livestock or wildlife (Glover and Conner 1988, Tyner and Purcell 1985). Nearly 78% of the forage consumed by livestock is produced from nonirrigated pasture owned by the livestock enterprises and, therefore, is not priced in a forage market (table 10). Thus, decisions to implement management practices to improve forage production will be based on the likely economic return associated with the final output, such as livestock or wildlife.

The amount of forage produced on public lands is set by multiple resource management objectives and public policy. Thus, the quantity produced on public lands will be a function of multiresource management for wild and domestic grazing animals and other resource outputs such as timber, water, recreation, and scenic beauty.

Assessing the forage produced nationally is difficult because forage production is not inventoried. Use, not production, is quantified when forage consumption estimates are derived from livestock inventories (table 10). Further, populations of wild grazing animals are not censused nationally as are livestock, thus deriving an estimate of the forage consumed by wild herbivores is also

difficult. Forage consumption represents only part of the forage produced on forest and rangelands. Physical inaccessibility may reduce grazing use of vegetation or, like the harvesting of timber on steep slopes, forage production may require additional expenses that make the utilization too expensive for the return. For example, the use of some areas by livestock often requires fencing to keep animals from grazing nearby palatable crops (Tyner and Purcell 1985), or areas may go unused by wild herbivores because of proximity to urban activities.

The national supply of forage is a function of the current and likely future management on forest and rangelands and the current and projected inventory of land available for forage production. Management results are influenced by the ecology of these forest and rangeland ecosystems. Past and current management includes grazing, timber harvesting, mining, cropping and the abandonment of cropland, and species introduction. These uses have and will affect the current production and potential production. Multiresource management requires a consideration of the tradeoffs in resource production. Future management practices, new technology, and eventually biotechnology, offer possibilities to enhance the future productivity of forest and rangelands. The availability of land for forage production is a function of the demand for land for other uses. Conversion of forest and rangeland to uses such as cropland or a non-revertible use such as urbanland decreases the land available for forage production.

Forage production projections will be derived from projections of the likely future technological improvements in forage production and projections of land available for forage production. The present chapter discusses the impact of technology and land availability as they have historically affected the production of forage at regional and national levels.

DYNAMIC NATURE OF ECOSYSTEMS

Range ecosystems are diverse and complex systems involving the flow of energy and the cycling of minerals through primary producers (range vegetation), herbivores (livestock, big game, nongame), and the detrital system (decomposers involved in the breakdown of organic matter) (fig. 17). The diversity of ecosystems across the United States is evident (fig. 2). These ecosystems have evolved to survive erratic precipitation, extreme temperatures, and natural disturbances (such as fire). As ecosystems respond to natural or human-caused disturbances, plant and animal species may change. These shifts in community structure are referred to as succession. The production of certain outputs, such as forage for wild and domestic herbivores, may require that the

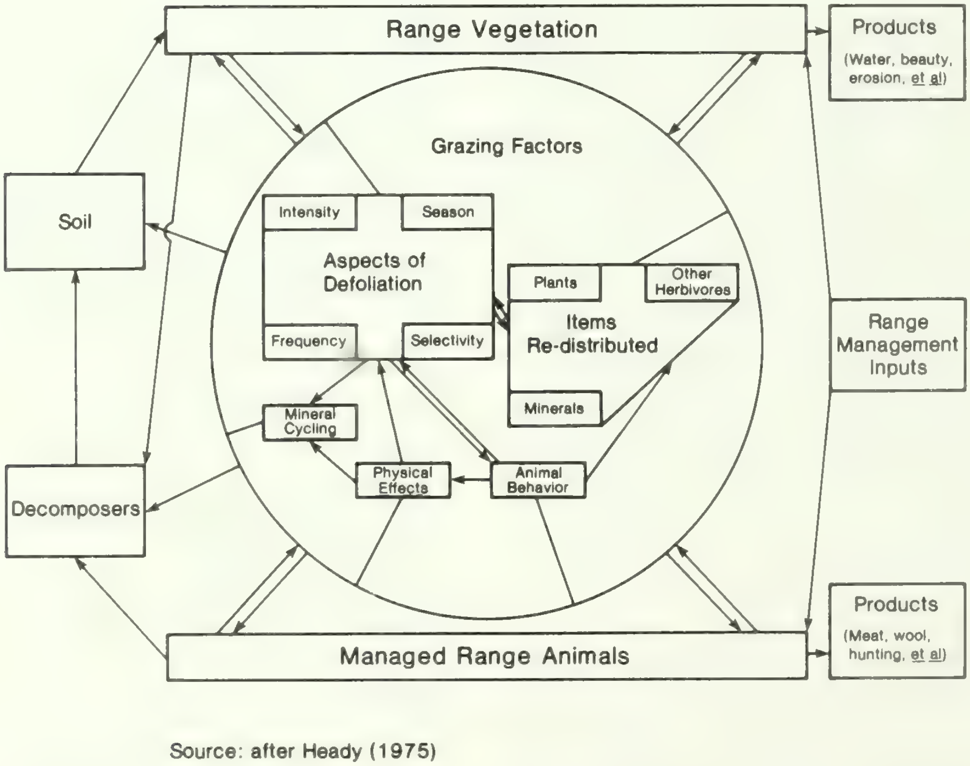


Figure 17.—Vegetation influences range animals and animals influence range through a number of interacting factors.

ecosystem be managed for an earlier stage than the Potential Natural Community (PNC). The biotic and abiotic processes within ecosystems induce a spatial heterogeneity across forest and rangelands (Risser et al. 1984) and link site-specific land management activities with the surrounding landscape. The management of spatial and temporal heterogeneity or biodiversity requires an understanding of the spatial and temporal aspects of natural disturbances such as fire, and management such as livestock grazing, timber harvesting, or recreation. Manipulation of these systems and the maintenance of biodiversity requires an understanding of the underlying ecological processes, their response to intensive or extensive management, and the consequences of management in the range and forest landscape.

Climate

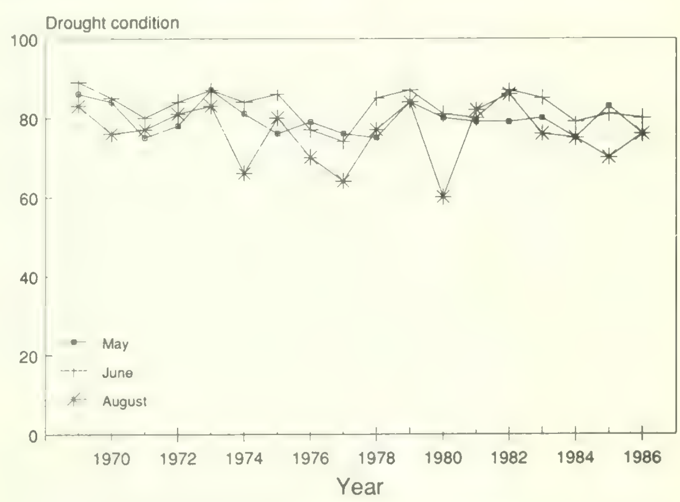
Weather and soil are the primary abiotic factors affecting forage production on forest and rangelands (Eckert and Klebesadel 1985, Herbel and Baltensperger 1985, Marbel et al. 1985, Moore and Lorenz 1985). Whereas the average precipitation of the United States is about 30 inches, annual precipitation is less than 1 inch in parts of the arid West, greater than 60 inches in southern Florida, and nearly 400 inches on some Hawaiian islands (Guldin in press). The eastern United States has an annual average greater than 40 inches, whereas most of the western United States receives less than 20 inches of precipitation annually. These averages suggest that different plants and different adaptations by plants to climate are made across the United States.

Average precipitation is derived from the tabulation of many years of data. Actual values of annual precipitation can range from zero to many times the annual average. The extremes, not the means, are the potentially harmful climatic events (Waggoner 1988). Drier climates are relatively more variable than wet ones, and changes in a drier climate will bring relatively more variation in annual precipitation (Waggoner 1988). Droughts can occur anywhere in the United States, and there is usually an area of drought each year (Trenberth et al. 1988). Western droughts have been numerous in the historical past: 1888-90, 1892-94, 1898-04, 1901, 1910, 1917, 1919, 1924, 1928-34, 1936, 1953-56 (Coupland 1958, U.S. Senate 1936). The more widespread dry years of the 1930's have been referred to as the "dust bowl years." Early records described the frequency of drought to be at least one or two years in every 10 years in western United States (U.S. Senate 1936).

Changes in environmental conditions within a growing season can be observed by using the national index of pasture and rangeland condition (U.S. Department of Agriculture 1987) (fig. 18). Measured on the first of May, June, and August, this national index reflects the seasonal variability in precipitation and temperature from 1969 to 1985. Good environmental conditions early in the year may deteriorate as precipitation decreases and temperature rises toward the end of the growing season, especially evident during August in 1974 and 1980 (fig. 18).

Environmental conditions vary not only year to year but also across the United States (fig. 19). The average 1975-84 pasture and rangeland condition was good to excellent in far western and northern parts of the United States, but conditions averaged only poor to fair in the northcentral and southern parts of the United States (U.S. Department of Agriculture 1987). These spatial patterns contrast with drought conditions in 1986 (fig. 19). In this year, poor to fair conditions occurred in parts of northeastern United States that averaged good to excellent over the previous 9 years. Excellent conditions favored the northern Great Plains which had averaged poor to fair over the previous 9 years. Below-average environmental conditions must be balanced by proper management to sustain the long-term productivity of these ecosystems.

The variability associated with weather, and consequently forage production, impacts land use. This relationship can be displayed by using the index of forage variability, which is the difference between the maximum and the minimum forage production in above and below average precipitation years, divided by the mean forage production (Sala et al. 1988). As the index approaches 1, fluctuations in forage production are as large as the average implying that forage production is highly variable. As the index approaches zero, production varies little from year to year. Within the Great Plains, the variability is greatest in the southwestern part



NOTE.--Numerical equivalent of condition: 80 and over, good to excellent: 65-79, poor to fair; 50-64, very poor; 35-49, severe drought; and under 35, extreme drought.

Source: USDA (1987)

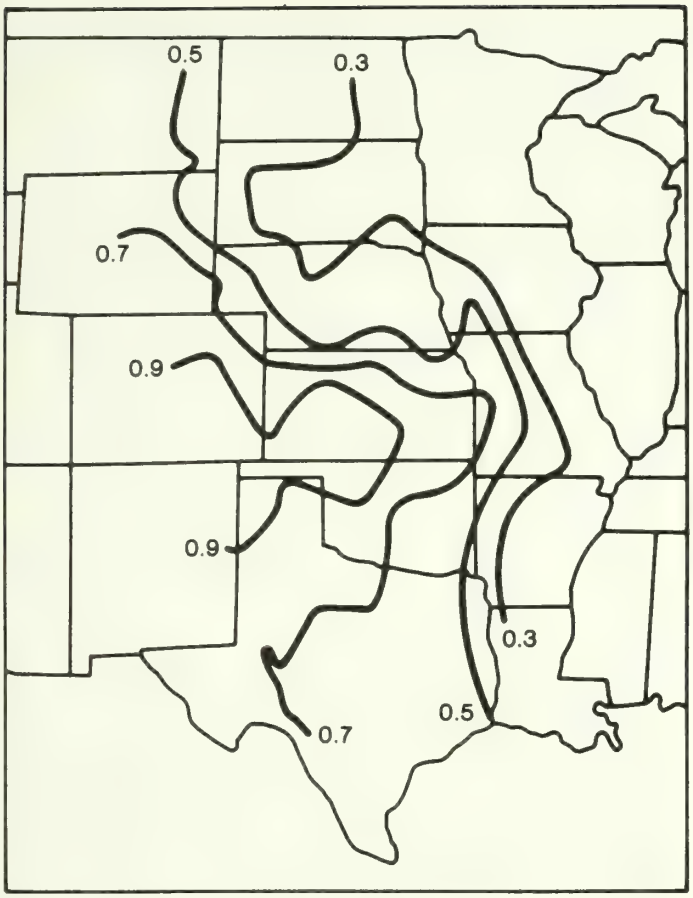
Figure 18.—Average pasture and range drought condition, as measured May 1, June 1, and August 1 in the United States.

Figure 19.—Pasture and range drought condition, June 1.

of the region, in the corner of the Colorado, New Mexico, Oklahoma, and Texas state boundaries (fig. 20). Variability decreases as one moves further east and north. Annual precipitation also increases in this direction. The shape of the area where variability is higher than 90% coincides with Borchert's (1950) wedge of spring and summer rainfall deficiency, characteristic of major drought years across central United States. Borchert (1950) showed that during drought years, precipitation tended to decrease toward the center of this wedge-shaped area and be near or above normal outside the wedge.

This area of greatest variability in forage production also coincides with the largest acreage enrollment of the most recent government crop set-aside program, the Conservation Reserve Program, and with the largest acreage enrollment of the 1950s government program, the Soil Bank program (Reichenberger 1987). Crop production in the Great Plains is subject to the same environmental variability as forage production. The management of these lands, the government agricultural programs, and the environment interact to influence changes in land use within this region and across the United States.

Although the results are unclear, evidence exists that the average air temperature will rise globally from 1 to 5° C because of past and current greenhouse gas emissions, such as carbon dioxide (U.S. Environmental Protection Agency 1988). These greenhouse gases absorb the earth's infrared radiation and warm the atmosphere. Future concentrations of these greenhouse gases based on forecasts of energy consumption, energy efficiency, and population growth are projected to double by the year 2030 (Mintzer 1987). Stringent energy conservation and efficiency would delay the doubling until 2075 (Mintzer 1987). The implication of this warming on the globe's climate is the focus of general circulation models, however, the resultant changes in local or regional climate are hard to forecast. Changes in climate will involve not only temperature changes, but also annual precipitation amounts and the seasonal distribution of this precipitation. For arid areas, the subtle shift



Source: after Sala and others (1988)

Figure 20.—Variability in forage production across the Great Plains as measured by the forage production index.

in increased variability of precipitation could potentially cause significant shortages in water for plants, animals and humans (Guldin in press, Waggoner 1988). These changes in climate could affect the current distribution of plants and animals, and the possibility exists for these climatic changes to occur more quickly than plants or animals could adapt (U.S. Environmental Protection Agency 1988). These changes imply the loss of plant and animal species, and the movement of plants into new ranges. These vegetation changes will imply shifts in land use, and economies dependent upon natural vegetation, such as rangeland, will be impacted by the potential future changes in climate. The projections for forage in this assessment are based on a future in which the climate follows historical trends. This assumption may not be met if the earth's climate changes rapidly. A number of studies have been initiated by the Forest Service (USDA Forest Service 1988a) and others (Committee on Earth Sciences 1989, Special Committee for the IBGP 1989) to examine the potential impacts of climate change.

Succession and Disturbance

Succession

The response of ecosystems to stress and disturbance is a function of the development and the past management of the ecosystem. Some of the different stresses under which ecosystems evolved include recurrent fire, grazing, no grazing by herbivores, periodic drought, high winds, and periodic flooding. As an ecosystem responds to repeated disturbances, soil, vegetation, and animal communities may follow a recovery path that is similar to the original path of ecosystem development. This response is particularly true if conditions are similar to those that existed when the ecosystem was developing (such as the periodicity of fire), and past use has not greatly altered one or more environmental factors (such as excessive erosion or introduced species). This path has been referred to as succession: the different plant and animal communities along this path are called successional stages (Cattelino et al. 1979, Drury and Nisbet 1973, MacMahon 1981, Odum 1971, Raynal and Bazzaz 1975, Shugart and West 1981). Major natural disturbances, steps in initiating revegetation after a disturbance, and the rate of recovery differ across ecosystems (MacMahon 1981). Different disturbances or stresses may induce an ecosystem to progress along different paths of recovery.

The management of ecosystems for multiple resource outputs requires an understanding of the individual ecosystem response to stress or disturbance. As different vegetation and animal species are present in each of the successional stages, the management for specific resource outputs may require managing for the stage that produces the desired output, and this successional stage may not be the PNC.

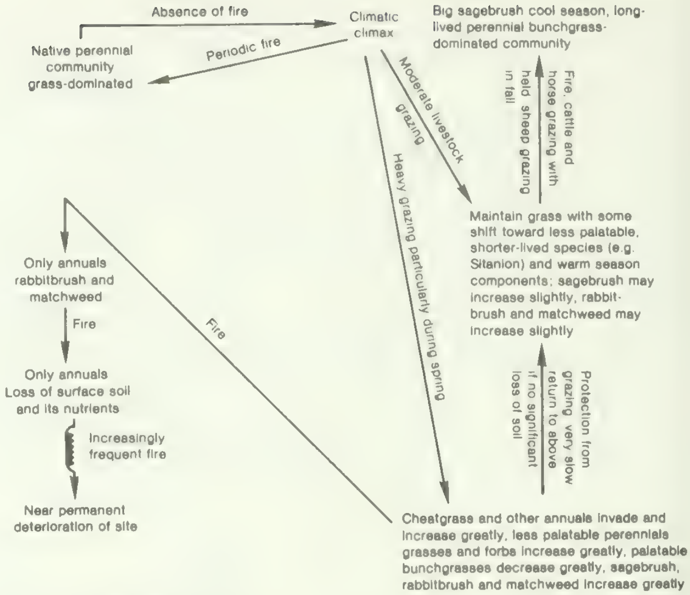
Natural Disturbance

Grazing animals have long been a part of forest and rangelands. Wild and domestic grazing animals influence primary production and other processes in the range ecosystem in a number of ways: defoliation of plants through eating and physical damage, digestive processes and the deposition of waste products, and movements such as bedding and trailing (Heady 1975, Pieper and Heitschmidt 1988). Defoliation from grazing has four aspects: (1) the intensity or degree to which a plant is defoliated, (2) the frequency or number of times a plant is grazed within a growing season, (3) the phenological stage of a plant when grazed, and (4) selectivity or the preference of the plant by the grazer or browser (fig. 17). These grazing influences imply management manipulations possible with grazers: adjust intensity, frequency, and seasonality of grazing, or change to a kind or class of animal with different diet preferences or grazing behavior (Heady 1975). Plant species consumed by cattle may or may not be the same plant species that deer, elk, goats, or sheep consume. Competition between grazing animals occurs when the dietary

overlap is great, little forage is available, or large numbers of animals are grazing the same area. Thus, the impact of the grazing animal will depend on the type or types of animal using an area.

Periodic fire is a part of the natural disturbance regime of North American grasslands (Sims 1988b, Wright and Bailey 1982). Although the presettlement frequency of fire in the Great Plains cannot be determined precisely, Wright and Bailey (1982) concluded that on level to rolling prairie grasslands, the fire frequency may have been every 5 to 10 years. The suppression of fire in the eastern parts of the prairie ecosystem has led to the encroachment of trees and shrubs from the eastern deciduous forests. Periodic fire also reduces competitive advantage of cool-season invaders such as Kentucky bluegrass and smooth brome and improves the palatability and nutritional value of the grazable forage (Sims 1988b).

Management can disrupt a natural disturbance cycle and change the ecology of an ecosystem, as seen in the lowland sagebrush semi-desert ecosystem. When periodically disturbed by fire and in the absence of heavy grazing, this ecosystem moved towards a native perennial grass-dominated community (West 1983). When disturbed by moderate livestock grazing and fire, the community of perennial grasses contain additional less palatable, shorter-lived, species of grass and increased amounts of sagebrush (fig. 21). Heavy grazing pressure reduced the occurrence of perennial grasses, allowing the increase of brush and the invasion by annual grasses, particularly cheatgrass (Young et al. 1987). These annual grasses initiate and complete their growth and the production of many seeds during the short period of spring moisture. During the dry season, these annual grasses provide a fine-textured fuel for wildfires that spread from shrub to shrub (Young et al. 1987). Annual grasses can withstand fires better than the perennial grasses, thus, grazing and increased reoccurring fires favor annual grasses over perennial grasses. A declining spiral of productivity ensues, and annual grasses replace perennial grasses in this ecosystem (West 1983). Removing the grazing animals does not foster the return of the historical successional dynamics once annual grasses dominate (fig. 21).



Source: after West (1983)

Figure 21.—Major pathways of succession in plant communities on lowland sagebrush semi-desert sites.

Forest Succession

In forest ecosystems, the first vegetation to appear after timber harvest is grasses and forbs, followed by shrubs (Thomas 1979). This transitory range offers forage for wild and domestic herbivores. The length of these early successional stages varies by the physical and biotic characteristics of the site. In southern forests, the grass and forb stage lasts less than 10 years. In western United States, weather or soil factors may extend these stages to 20 to 40 years. Eventually, trees begin to colonize this previously forested site and reduce sunlight reaching the forest floor. Management activities can shift understory vegetation to an earlier or later successional stage depending on the current status (fig. 22). Shrub control with herbicides can facilitate tree growth by reducing shrub competition, thus encouraging successional processes in forest ecosystems. Grazing in the grass-forb stage retards shrub and tree growth, thus retarding succession. The many types of herbivores will differentially impact species composition and succession (fig. 22). The timing of management applications, such as fertilization or controlled burn, influences the direction of change also (fig. 22). Timber management practices, such as thinning, open up the forest canopy, allowing sunlight to reach the forest floor, and increase grass and forb production.

On commercial forestlands, the biological environment is manipulated to intensively grow trees. Where environmental factors are not limiting vegetation growth, a possibility exists to maximize multiresource production on these sites. The introduction of pasture grasses under timber plantations and irregular spacing of trees can enhance the production of understory forage on these commercial forestlands (Lewis 1984). The introduction of grazers to reduce grass, forb, and shrub competition with trees can increase the diameter growth of small trees 8-14% (Mosher 1984). The multiple use management of timber plantations can have benefits in terms of increased profit, biological control of competing vegetation, and recreational benefits from wildlife (Pearson and Cutshall 1984).

Changes in the Resource Base

The historical and current management of forest and rangeland has changed the composition of plant and animal species in many ecosystems. Although livestock grazing has received much focus as a primary change agent, other uses have also affected forest and rangelands. All land in the United States now in cropland or

Management action	Grass-forb	Shrub-seedling	Pole-sapling	Young	Mature	Old growth
Shrub control:						
• Herbicides	▶	▶	▶	◀	◀	◀
• Mechanical control	◀	◀	NA	◀	◀	◀
Controlled burn:						
• Cold burn	◀	◀	▶	▶	◀	◀
• Hot burn	◀	◀	◀	◀	◀	◀
Fertilization	◀	▶	▶	▶	▶	O
Grazing and browsing (moderate rates):						
• Cattle and sheep	◀	▶	O	O	◀	◀
• Goats	O	◀	O	O	◀	◀
• Deer and elk	◀	▶	O	O	◀	◀
Planting:						
• Trees	▶	▶	NA	NA	▶	▶
• Shrubs	▶	◀	NA	NA	NA	NA
• Grasses-forbs	▶	◀	NA	▶	▶	O
Regeneration cut:						
• Clearcut	NA	NA	NA	◀	◀	◀
• Shelterwood	NA	NA	NA	▶	◀	◀
• Seed tree	NA	NA	NA	◀	◀	◀
Salvage	NA	NA	◀	◀	◀	◀
Thinning (including single tree selection harvest)	NA	▶	▶	▶	▶	O

▶ advances succession
◀ retards succession
O no effect on succession
NA not applicable

Successional stage condition

Source: after Thomas (1979)

Figure 22.—Anticipated changes in successional stage resultant from management activities on forest land.

urban use was at one time forest or rangeland (fig. 8). Presettlement vegetation was probably near or at climax, with an occasional disturbance by natural catastrophe causing the vegetation to return to an early stage and succession (Wagner 1978). Settlers entered these ecosystems, removing the natural vegetation to make room for food crops, harvesting timber for fuel and shelter, and replacing wild herbivores with often too many domestic animals (Box 1978, Heady 1975, Rowley 1986). During 1880-1900, ecosystems in California were subjected to a combination of management stresses: severe overgrazing from high livestock numbers, the largest acreages plowed, the least informed forest practices, and the most extensive burning in the history of California (Heady 1975).

An overestimation of the productive capacity of semiarid and arid lands resulted in many failed attempts to homestead on 160 acres in the Great Plains during the late 1800s. Abandoned farm fields in western areas can take nearly 50 years to develop natural vegetation similar to the surrounding rangelands (McGinnies 1983). The more recent conversion of rangeland into cropland has been facilitated by technological developments, such as four-wheel drive tractors, electronically controlled harvesters, pesticides, fertilizers, and hybrid plant species. As a result of this new technology, the yield of wheat per inch of precipitation in the Great Plains has nearly tripled since 1930 (Lacey 1983 citing Sampson 1981). New arid land cropping technologies were given as a reason for the plowing of rangelands in the 1970s (Hendricks 1983).

Changes in riparian zones can be attributed to several factors including the number and distribution of natural and introduced large grazing animals, the alteration of flow caused by diversion of water for irrigation and reservoir storage, the multiple use of watersheds, and the present exploration for oil and gas (Skinner 1986). Erosion has been a part of the historical landscape, as large wildlife (bison) herds sought the use of water in these riparian zones (Skinner 1986). Past management activities such as channelization, water storage facilities, and vegetation clearing, in combination with livestock grazing, have resulted in a loss of 70% of the original area of riparian vegetation in the United States (Swift 1984). However, some land management activities created riparian zones where none previously existed (Skinner 1986). Cottonwood bottomlands in the northeastern Colorado were rare along the South Platte River, until large ranching operations began irrigation. The cottonwood population peaked during the 1950s but has declined since then primarily because of water management which has restricted overbank flooding (Crouch 1979).

Concern about the impacts associated with the severe overgrazing during the early 1900's (U.S. Senate 1936)—degraded rangeland, gully erosion, and loss of riparian habitat—led to management that has generally improved range condition since 1935 (Busby 1979). Recommended stocking rates and grazing systems were developed and implemented to efficiently utilize upland vegetation. These grazing systems often overutilized riparian vegetation, while maintaining the condition of rangeland as a whole (Platts 1986). Many Great Plains woody stands no longer exist in riparian areas and have been replaced by grasses and forbs. The deterioration and lack of reproduction within the remaining woody stands is attributed mostly to past heavy cattle use (Boldt et al. 1979). Along the lower Colorado River, Ohmart et al. (1977) estimated that the cottonwood community had declined from 5,000 acres in historical times to scattered groves containing a few mature individual trees. Livestock have impacted the riparian zones by trampling of the streambanks, causing loss of vegetation cover, lowering the water table, and making stream channels wider and shallower (Busby 1979, Kauffman and Krueger 1984, Platts 1979).

The introduction of exotic plant species either purposefully or accidentally has had and continues to have significant impact on the Nation's landscape. As invaders, exotic plant species can diminish forage production, but some planted exotics can enhance forage production as valuable forage, such as crested wheatgrass. In

Illinois, 811 species or 29% of the state's flora are naturalized from foreign countries (Harty 1986). Lehmans lovegrass in Arizona and buffel grass in Texas, introduced as new forage species, have invaded native stands and now dominate certain areas. The accidental introduction of leafy spurge, about 100 years ago, now means an annual loss of $20 to $30 million in forage and beef production for western farmers and ranchers, including the costs of chemical control (Wood 1987). The plant species saltcedar, introduced as an ornamental, has successfully invaded riparian areas in western United States (Horton 1977). In this situation, two management activities facilitated the change in the landscape: the introduction of an exotic plant species, and the manipulation of the flooding regime in the riparian zone. At a larger scale, government crop reduction programs have facilitated the planting of valuable, but introduced, pasture species.

The accidental or purposeful introduction of animal species includes carp, nutria, house mouse, Norway rat, European wild boar, European starling, rock dove, balsam wooly aphid, and gypsy moth (Harty 1986). Large grazing animals from other parts of the world, such as kudu and impala, are now part of many game ranches in western United States (U.S. Congress, Office of Technology Assessment 1986a). These animals provide income to ranchers, genetic reserves for threatened and endangered species, and recreational opportunities.

Brush invasion is the encroachment of undesirable perennial woody plants in ecosystems in which these shrubs are not part of the climax plant community, or the increase in shrub density where the natural density is low (USDA Soil Conservation Service 1987c). Shrubs species most common in this category include mesquite, juniper, sagebrush, several species of oak, saw-palmetto, creosote bush, and chaparral shrubs. Under dense shrub production, grass and forb production is lessened and soil erosion increases (USDA Soil Conservation Service 1987c). Invasion by shrub species has had negative impacts on habitat for wildlife species such as bighorn sheep, pronghorn, sage grouse, masked bobwhite quail, and northern aplomado falcon. Shrub invasion has had positive impacts on habitat for some wildlife species, such as mule deer (Flather and Hoekstra in press). Brush management could enhance forage production on almost 81 million acres of nonfederal rangeland. On over 17 million acres of nonfederal rangeland, brush control and the reestablishment of desirable forage plants by seeding is considered necessary to reestablish a productive rangeland ecosystem (USDA Soil Conservation Service 1987c).

VEGETATION MANAGEMENT

Existing Technologies

Resource managers manipulate the processes of energy flow and nutrient cycling in order to obtain the production of forage for livestock and wildlife and sufficient plant cover to protect the soil from wind and water erosion (figs. 17 and 22). Management decisions involve determining the suitability of the vegetation for different uses, designing and implementing range improvement practices, and manipulating the distribution, intensity, and seasonality of grazing by wild and domestic herbivores. Range improvements include special treatments, developments, and structures that can improve range forage quality or quantity or facilitate the efficient use of forage by grazing animals (Vallentine 1980).

The analysis of forage production to produce a specific output such as livestock or wildlife on an individual enterprise requires an analysis of the production system within which forage is an input (Workman 1986). The analysis of forage production requires a recognition of interrelations among the forage itself, the animal that grazes or consumes it, the soil/land resource, and the enterprise that must plan for economic survival (Tyner and Purcell 1985). This analysis reflects site-specific concerns such as the tradeoff between range improvement practices and the expected return in domestic or wildlife production. The successful implementation of these improvement practices must sufficiently increase the final output that is marketed from the enterprise before the practice is cost effective.

Practices that have been used to improve the management of rangelands may be broadly grouped: promoting desired plant species; controlling undesirable plant species, manipulating the distribution, intensity, and seasonality of grazing by wild and domestic herbivores; and controlling undesirable animal species (Vallentine 1980; U. S. Congress, Office of Technology Assessment 1981). Technology to enhance the production of herbivores is discussed in Chapter 3. Technology to enhance vegetation production includes capital intensive techniques for shrub removal or less intensive practices such as fire (table 11). Reseeding and interseeding practices have been used to replace or enhance the composition of desirable forage species when the native vegetation is of poor quality or lacking in quantity. For example, winter ranges of mule deer and domestic sheep can be enhanced by plantings or seedings of the recently released 'Hobble Creek' low-elevation mountain big sagebrush (Welch et al. 1986).

Lands that have undesirable species can be controlled by a number of mechanical, chemical, and biological methods, but success rates vary with environmental conditions and application. Mechanical plant control has included crushing, uplifting or knocking down plants, and plowing the root zone of undesired vegetation (table 11) (Vallentine 1980). The use of fire in controlling undesirable plant species has the advantages of being inexpensive and effective against non-sprouting species. Until the late 1940s and early 1950s, chemical control was limited to individual-plant treatments because most herbicides were not highly selective (Scifres 1977). Since then, the number of chemicals and control methods has increased (table 11). Aerial spraying of chemicals is particularly advantageous for rangelands with difficult terrain. The future development of chemicals that are highly specific in their effect is important to selectively manage for desired species. Biological control which is

Table 11.—Status of development and application of facilities and equipment used to manipulate vegetation for managing and improving range ecosystems of the Great Plains.

Facility or equipment item[1]	Status of development[2]	Extent of application[3]
A. Mechanical plant control		
1. Plant root extraction by plows or grubbers	3	2
2. Brush clearing by rakes, chains or rails	3	2
3. Choppers and shredders	3	2
4. Mowers	3	3
5. Handtools	3	3
B. Herbicide application		
1. Fixed-wing or helicopter sprayers	3	2
2. Vehicle mounted boom sprayers	3	2
3. Other vehicle mounted applicators	2,3	2
4. Mist sprayers	3	2
5. Subsoil injectors	3	1
6. Tree injectors	3	2
C. Seeding		
1. Broadcast seeders		
a. Fixed wing or helicopter spreaders	3	2
b. Seed dribblers	3	3
c. Blower or rotary spreaders	3	3
d. Steep slope scarifier seeder	3	1
e. Hydraulic seeder-mulchers	3	2
f. Grass seeder (spreader with cultipacker)	3	2
2. Drills		
a. Grain drills	3	3
b. Heavy-duty grain drills (pasture drills)	3	2
c. Rangeland drills	3	2
d. Presswheel drills	3	2
e. Seeder for brush littered range	2	1
3. Interseeders		
a. Range interseeders	3	2
b. Tiller seeders	3	1
c. Interseeder for rocky and brushy areas	3	2
4. Others		
a. Sodders or spriggers	2	1
b. Tree and shrub planters	3	1
D. Fire management		
1. Ignition devices	3	2
2. Fireline plows	3	2

[1]Equipment and facilities are grouped according to their principal use. Many have a variety of applications.
[2]Status of development:
1 = Undeveloped.
2 = Various stages of development, not available for general use.
3 = Fully developed and available for use; refinements may be made in existing equipment.
[3]Extent of optimum application:
1 = None or very limited
2 = Significant, but incomplete
3 = Complete or near complete
Source: After Lewis and Engle (1982).

the study, importation, augmentation, and conservation of natural enemies (Dahlsten 1986), can be very successful against exotic plant species. One of the earliest successes occurred in the mid-1940s when *Chrysolina* beetles were introduced into northern California to control St. Johnswort. By 1958, St. Johnswort had been reduced to less than 1% of its former abundance (Vallentine 1980). The use of grazing animals such as livestock to control weedy species is a promising area of research.

Integrated pest management (IPM) is the selection of two or more compatible pest suppression tactics for control of a single pest organism: animal, plant, insect, or

pathogen pest (Johnson 1987). Although IPM offers potential treatments for rangeland pests, managers are confronted with problems concerning the various costs and benefits of individual pest management options for rangelands. Data on the economic thresholds for selecting control methods for nearly all pests are absent (Capinera 1987). When control methods are examined for animals such as prairie dogs which have long been considered pests, research suggests that the animals may not be economical to control and are important in the enhancement of wildlife diversity and for sport hunting (Uresk 1987).

Although many technologies currently are fully developed and available for use, the extent of their implementation is often lacking (Lewis and Engle 1982). Within the Great Plains, the only mechanical plant control methods considered to be nearly complete in optimum application are mowers and handtools (table 11). Heavy equipment has been applied but not as extensively. Seeding equipment developed for steep slopes or brush-littered rangelands is less likely to be implemented than other seeding technologies for more accessible rangeland. The extent of technological application appears poor for capital-expensive treatments (heavy equipment) and for technologies for areas of likely low return (steep slopes or woody rangelands). An evaluation of improvement practices within the depressed livestock market of the last few years has not suggested the profitable implementation of many range improvement practices (Pope and Wagstaff 1987b).

Future Technologies

The future productivity of agriculture and livestock could potentially be increased by the development and implementation of 150 existing and potential technologies (U.S. Congress, Office of Technology Assessment 1986b). These technologies span improvements in plants such as genetic engineering, plant physiology, improvements in disease and pest management, and monitoring of the environment and labor-saving technologies (table 12). The future availability of such technology was based on a real rate of growth in research and extension expenditures of 2% per year, and the continuation of all other forces that have shaped past development and adoption of technology (U.S. Congress, Office of Technology Assessment 1986b). Decreases or increases in research and extension expenditures shift the future availability of these technologies (table 12). Technologies developed for croplands that can easily be implemented on rangelands and technologies developed for grain crops will impact forage production earliest. Environmental monitoring devices, communications and information management, and telecommunication devices are available today. Computer software and database systems can handle large amounts of data and aid in farm/ranch management decision analyses. Developments in this information management technology will enhance research and development in forest and rangeland management (Wisiol and Hesketh 1987).

Technologies to improve disease resistance, weed control, and the management of insects and mites were also forecast to be available before 2000 (table 12). The enhancement of photosynthetic efficiency and plant growth regulators were also available by 2000. Understanding drought resistance and tolerance, and improving water use efficiency through recombinant DNA were not forecast as being available until 2000. Plant technologies were seen as lagging behind animal technologies, and significant improvement in primary production would not occur until the year 2000 (U.S. Congress, Office of Technology and Assessment 1986b). Animal technologies will affect the production of livestock and the consequent demand for forage (Chapter 3).

The potential impact of these technologies on range plant production involves economic and social factors. The Soil Conservation Service (SCS) reported that an economic analysis of the range livestock industry showed that rangeland is more responsive to intensive management practices than to capital-intensive practices (USDA Soil Conservation Service 1987c). Much of the technology identified in table 12 is capital-intensive; however, few range improvement practices have proved profitable in the recent livestock market.

The extent that technology could improve forage production is viewed as highly significant in many parts of the United States. The application of existing technology could potentially increase forage production 100% to 200% in Southwestern ecosystems (Dwyer 1982). Similar estimates of potential improvement in range forage production were made for the Pacific Northwest grazinglands by Box (1982). In contrast, significant improvements in forage production in the Northern (NO) region will depend on the development of technologies to produce multiple resources from forested lands (Byington 1982).

AVAILABILITY OF GRAZINGLAND

Past Legislation and Land Use

Legislation has affected the management of lands in private and public ownership (table 13) and thus, indirectly, the supply of forage nationally. The early homestead acts (1862, 1873, 1877) transferred public domain land to private individuals under certain management conditions (Smith 1979). Government crop-acreage control programs can influence the acreage of land available for forage production. This influence was evident in the Soil Bank (1956) that allowed grazing and the Conservation Reserve Program (CRP) (1985) that did not allow grazing.

Grazing on public lands was important in the start of the livestock industry in western United States (Blaisdell and Sharp 1974, Rowley 1986). The use of federal lands for grazing was first regulated on forest preserves in 1897, and on public domain lands in 1934 (table 13). The poor condition of the federal lands before this time has been discussed by a number of authors (Blaisdell and Sharp 1974, Box 1978, Rowley 1986, Stoddart et al. 1975). This regulation of grazing on federal lands helped to control excessive grazing (Rowley 1986). Legislation

Table 12.—Emerging technologies for plant production and likely year of introduction under three future environments for technological development.

Technology	Technology environments: More new technology[1]	Most likely[2]	Less new technology[3]
Genetic engineering:			
Microbial inoculums	1990	1990	Never
Plant propagation	1983–90	1983–90	>1990
Genetically engineered cereals	1995	2000	2010
Enhancement of photosynthetic efficiency:			
Basic process of photosynthesis	1983	1983	1983
Photosynthetic control	1983–90	1983–90	1983–2000
Photosynthetic molecular biology and genetics	1990–2000	1990–2000	1990–2000
Mechanisms of response and adaptation to stress	1990	1983–95	2000
Plant growth regulators:			
Controlling growth/development	1984	1984	1985
Disease and insect resistance	1986	1988	1990
Overcoming environmental stresses	1986	1988	1990
Plant disease and nematode control:			
Breed cultivators	1984	1984	1984
Genetic engineering	2000	2000	2025
Bacteriocides, fungicides, and nematicides	1988	1990	2000
Biocontrol agents	1985	1990	2010
Management of insects and mites:			
Chemical controls	>1995	2000	>2000
Genetic engineering			
Pathogenic chemicals	1995	2000	2005
Plants	2000	2005	2010
Information processing	1984	1984	1984
Weed control:			
Bioregulation through chemical and biological technology	1984-2000	1984-2000	1984-2000
Allelopathic chemicals	1990	1995	2000
Crop tolerance and susceptibility to control agents	1992	1998	>2000
Biological nitrogen fixation:			
Improved strains of rhizobia	1984	1984	1984
Stress-tolerant rhizobia	1987	1990-95	1995-2000
Legumes more active in nitrogen fixation (plant breeding)	1990-95	1990-95	1990-95
Nitrogen-fixing cereals	>2000	>2000	>2000
Chemical fertilizers:			
Increasing efficiency of nitrogen use	1990	1995	2000
Decreasing energy required	1980	1980	1980
Processing of lower quality phosphate rock into fertilizers	1990	1990	1990
Ammonia from coal	1995	2000	2000
Communications and information management:			
Communication networks, data terminals, software	1985	1985	1985
Manufacturing management systems	1987	1990	2000
Expert systems	1990	1992	1997
Monitoring and control:			
Sensors, controllers, displayers	1984	1984	1984
Water and soil-water-plant relations:			
Understanding drought resistance/tolerance	2000	2020	2050
Plant breeding	1984	1984	1984
Biotechnology:			
Water use efficiency	2010	2030	2050
Water management	1984	1984	1984
Photovoltaic systems	1995	1995	2010

Table 12.—Continued

Technology	Technology environments: More new technology[1]	Most likely[2]	Less new technology[3]
Soil erosion, productivity, and tillage:			
Conservation farming systems	1995	1995	1995
Assessing erosion and its impact	1995	1995	2000
Reclaiming lands	1995	1995	>2000
Organic farming:			
Biocides	1984	1984	1984
Reduced soil erosion	1984	1984	1984
Self-sufficiency for nutrients	1984	1984	1984
Minimum tillage with minimal biocide use	1990	1990-95	2000
Rotations			
Use	1984	1984	1984
Knowledge	1990	1990-95	2000
Labor-saving technologies:			
Robotic farming of grains	1995	2000	2010
Crop separation, cleaning, and processing:			
New methods for separating and cleaning grain	1995	1995	1995
Infield or onfarm processing:			
Forage	1990	1990	2000
Oilseed	1984	1984	1984
Engine and fuels:			
Adiabatic compression ignition engines with turbocompounding	1990	1990	1990
Electronic engine controls	1985-86	1986	1986
Alternative fuels			
Grains	1984	1984	1984
Cellulose	1995	2000	2010
Land management:			
Conservation tillage	1984	1984	1984
Controlled traffic farming	1987	1990	1995
Customed-prescribed tillage	2000	2005	2020
Multicropping	1984	1984	1984
Telecommunications:			
Digital communication	1995	2000	2010
Fiber optics	1990	2000	2010
Personal computers	1985	1985	1985
Videotex and teletext	1985	1985	1985
Value-added networks	1985	1985	1985
Integrated services digital network	1990	1990	>2000
Remote sensing	1985	1985	1985

[1] *Assumes to year 2000: (1) a real growth rate in research and extension expenditures of 4%, and (2) all other factors more favorable than those of the most likely environment.*
[2] *Assumes to year 2000: (1) a real rate of growth in research and extension expenditures of 2%, and (2) the continuation of all other forces that have shaped past development and adoption of technology.*
[3] *Assumes to year 2000: (1) no real rate of growth in research and extension expenditures, and (2) all other factors less favorable than those of the most likely environment.*
Source: After U.S. Congress, Office of Technology Assessment (1986b).

has continued to affect the management of federal lands (table 13). Recent legislation has emphasized the multiple use of federal lands (1960), the need to examine potential impacts of management (1969), the management of wild horses and burros as part of Forest Service (FS) and Bureau of Land Management (BLM) grazing management (1971), the decadal assessment of current and future production of natural resources on all forest and rangelands with the development of a national program for FS (1974), and the need for a planning process on all National Forest System (NFS) lands and all BLM-administered lands (1976). These factors affect the supply of forage as it is allocated to each of these uses on federal lands.

Table 13.—Legislation affecting the management of forest and rangelands in the United States.

Year	Law	Consequences
1862	Homestead Act	Encouraged settlement of West.
1873	Timber Culture Act	Settlement of 160 acre if trees planted.
1877	Desert Land Act	Land sold for 25 cents per acre if irrigated and cultivated for 3 years.
1897	Organic Administration Act	Regulated use of Forest Preserves (est. 1891)
1905	Transfer Act	Forest reserves transferred from USDI to USDA; created the Forest Service.
1906	Meat Inspection Act	Governed the slaughtering, packaging, and handling of meat shipped intrastate.
1916	Federal Farm Loan Act	Farmland banks created.
1920	Mineral Leasing Act	Allowed the Government to lease national forest lands for mining.
1924		Gila Wilderness, NM, became first official wilderness in NFS.
1928	Wool Standards Act	Appropriated funds for wool standards.
1928	McSweeney-McNary Act	Established a program of forest research.
1934	Taylor Grazing Act	Designated grazing on public domain lands to be regulated by the BLM.
1950	Cooperative Forest Management Act	Federal cooperation with states to provide technical services to private forest landowners.
1952	Independent Agencies Appropriation ACT	User fees must be self-sustaining, uniform, fair and equitable to public and user.
1954		National Grasslands added to Forest Service
1956	Agricultural Act	Financial assistance to farmers converting cropland to conservation uses (Soil Bank).
1960	Multiple-Use and Sustained Yield Act	National forest management to recognize multiple resources and uses.
1964	Wilderness Act	Creates National Wilderness Preservation System.
1964	Trade Agreement	US-Australia agreement limits Australian export of beef, veal, and mutton.
1964	Tariff Act of 1930 Amendment	Allowed the free importation of certain wild animals and imposed quotas on certain meat and meat products.
1969	National Environmental Policy Act	Analyses required for all management potentially affecting the environment.
1971	Wild Free-Roaming Horse and Burro Act	Management of wild horses and burros on FS and BLM lands now the responsibility of FS and BLM.
1973	Endangered Species Act	Federal management must not jeopardize the existence of endangered plant or animal species.
1974	Forest and Rangeland Renewable Resource Planning Act	Assessment of current and future production of natural resources on all forest and rangelands and development of a national program.
1974	Federal Noxious Weed Act	Provide for control of noxious weeds.
1976	Federal Land Policy and Management Act	Requires planning on BLM lands.
1976	National Forest Management Act	Requires planning process on all NFS lands.
1976	Beef Research and Information Act	Establish a program of research, information, and promotion for beef cattle and beef products.
1978	Public Rangelands Improvement Act	Grazing fee formula for FS and BLM, and requires analysis of fee in 7 years.
1978	Forest and Rangeland Renewable Resources Research Act	Authorized USDA research to be conducted on renewable resources.
1985	Food Security Act	CRP, sodbuster, swampbuster, conservation compliance.

Source: Smith (1979); USDA Forest Service (1983b); USDA Forest Service, and USDI Bureau of Land Management (1986).

Land Use at the National Level

Land Use Inventories

A series of land use inventories based on available statistics has been summarized by the Economic Research Service and its predecessor agencies (Frey 1973, 1979, 1982; Frey and Hexem 1985; Frey et al. 1968; Wooten and Anderson 1957; Wooten et al. 1962). Categories and area coverage have been generally comparable since 1945. This compilation of land use data from public agencies such as FS, Bureau of Census, BLM, and SCS provides a useful framework within which changes in the supply and demand for land can be analyzed (Frey and Hexem 1985).

Major land uses include forest land, cropland, and pasture and rangeland. The interpretation of these land-use trends is based on land use, not land cover. In this historical data, land with tree cover that is designated as wilderness is removed from the forest land category. Thus, data for the major land use categories of forest land, and pasture and rangeland do not include military lands, national parks, or wilderness area. These land-use inventories do not separate pasture from rangeland, thus long-term trends are available only for this combination. Historical records are also kept on special-use areas, such as roads, railroad rights-of-way, airports, federal and state parks, wilderness areas, wildlife refuges, defense, and industrial areas.

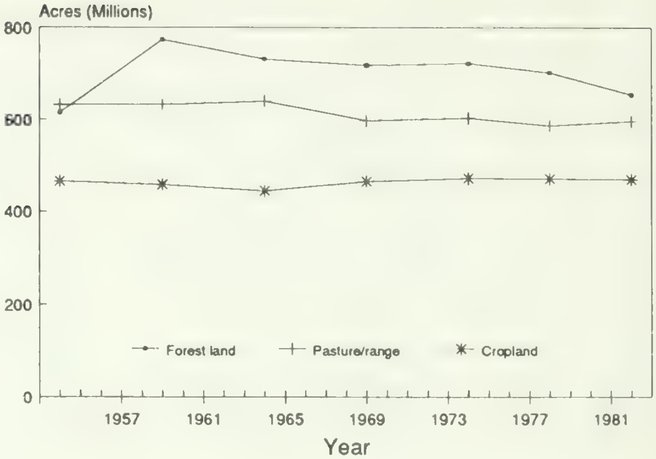
Major Land Use Trends

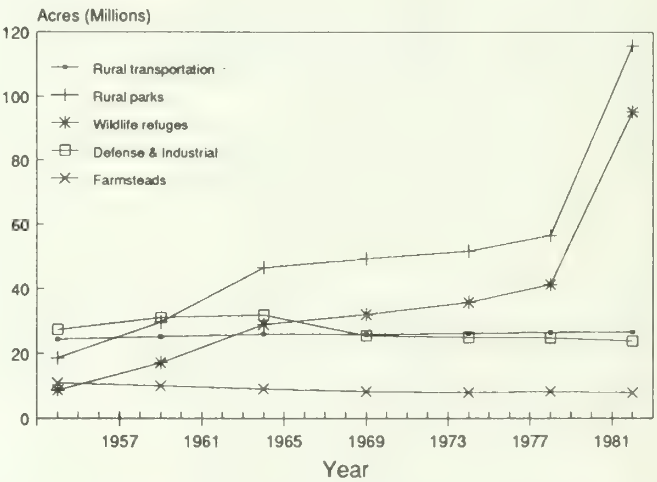
Since 1954, shifts in major land uses have been minor at the national level (fig. 23). The increase in forest land between 1954 and 1958 is the result of the inclusion of Alaska's lands with the U.S. land base. Since 1958, forest land conversions to land uses such as crop, pasture, and urban has resulted in a decrease in forest area. The legislated conversion of forest land into wilderness contributes to the decline in forest area and the increase in rural parks and wildlife refuges (fig. 23). Total cropland has remained fairly constant at around 450 million acres. Pasture and rangeland together form the second largest use of land in the United States. Acres in this land use category show a decline of 4% over this period, because this land has been converted to other uses such as agriculture or urban.

The most rapid land use change has been in the rural parks and wildlife refuges (fig. 23). This increase is associated with the Wilderness Act of 1964 (table 13) and greater interest in recreation and wildlife (Cordell in press, Flather and Hoekstra in press). In 1982, national and state parks and related areas totaled 116 million acres, and federal and state wildlife agencies administered an additional 95 million acres.

Trends in the Availability of Grazingland

The Nation's grazingland base includes forest land, rangeland, pasture, and cropland used for pasture.





NOTE.--Data from periodic inventories. Most recent inventory: 1982.

Source: Frey (1973, 1979, 1982), Frey and Hexem (1985), Frey et al. (1968), Wooten and Anderson (1957), Wooten et al. (1962)

Figure 23.—Major uses of land in the United States, 1954-1982.

Changes in this base[4] have been estimated over time (Frey and Hexem 1985). Grazing available on forest land is estimated from the area in open forests, arid woodlands, and lands reverting to forest which have forage. Changes in nonforested pasture and rangeland include cropland pasture. Frey and Hexem (1985) reported that between 1969 and 1982, grazingland had declined 8%. Declines were steady in both forest grazing and nonforested pasture and rangeland.[5]

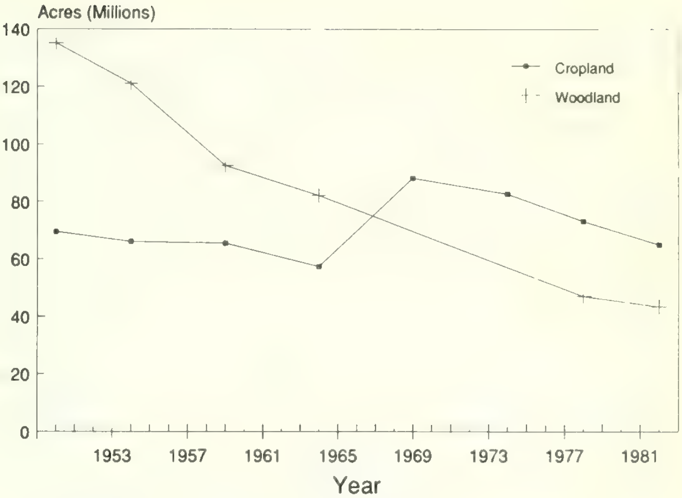
[4]*These estimates exclude land on which grazing occurred before or after crops were harvested, and areas totaling about 60 million acres in federal grazing districts and range allotments that have little value for grazing but which are intermingled and managed with productive federal range. In addition, these estimates do not include special land uses such as wilderness or wildlife refuges.*

[5]*Nonforested pasture and rangeland in this historical time series include cropland used for pasture as well as pasture and rangeland.*

Several forces combine to cause the long-term decline in pasture and rangeland: (1) fluctuating demands for crop products shift acres between cropland and other uses such as pasture and rangeland, particularly in the South; (2) withdrawal of land for recreational, wildlife, and environmental purposes, particularly in the western United States; and (3) withdrawal of land for urban areas across the Nation (Frey and Hexem 1985). Since 1949, 41 million acres of pasture and rangeland have been converted to other uses. Since 1969, this decline appears steeper because 30 million acres have been converted to other uses in only 13 years. Although these estimates reflect some inconsistencies in classification and measurement, Frey and Hexem (1985) maintained that a long-term decline has occurred in pasture and rangeland, and that the 30 million acres converted to other uses since 1969 was more representative of the long-term rate of decline. This decline represents an annual loss of 0.33% in total nonforested pasture and rangeland.[6]

Cropland used for pasture, one component of pasture and rangeland area, fluctuated from a record low of 57 million acres in 1964 to a record high of 88 million acres in 1969 (fig. 24). These fluctuations correspond with government set-aside programs for crop surpluses. Cropland used for pasture represents a small total acreage when compared with the pasture and rangeland total, 65 million compared with the 598 million acres reported by Frey and Hexem (1985) for 1982. This cropland, however, is a highly productive component and represents the only available grazingland in some areas in certain seasons. The sensitivity of this grazing resource to conversion to crop production varies with the region. Cropland pasture makes up a proportionally larger amount of land in fertile agricultural areas such as the Corn Belt (Iowa, Illinois, Indiana, Ohio, and Missouri). In other areas such as the Appalachian region, cropland pasture is associated with small, irregularly shaped, and scattered fields not as likely to be converted to crop production (Frey and Hexem 1985).

Forest grazing by livestock has declined 50% since 1949. Although these estimates do not include special land uses such as wilderness or wildlife refuges, this decline in forest grazing does include changes in forest species such as improved commercial timber stock, increases in stand density, and improvements in livestock feeding and forest management practices (Frey and Hexem 1985). Areas designated as wilderness on NFS lands are grazed by wildlife and, if previously permitted, livestock. Thus, the historical forest grazing acreages



NOTE.--Data based on periodic inventories. Most recent inventory: 1982.

Source: USDC, Census of Agriculture (1984)

Figure 24.—Area of woodland pasture and cropland used only for pasture or grazing in the United States, 1950-1982.

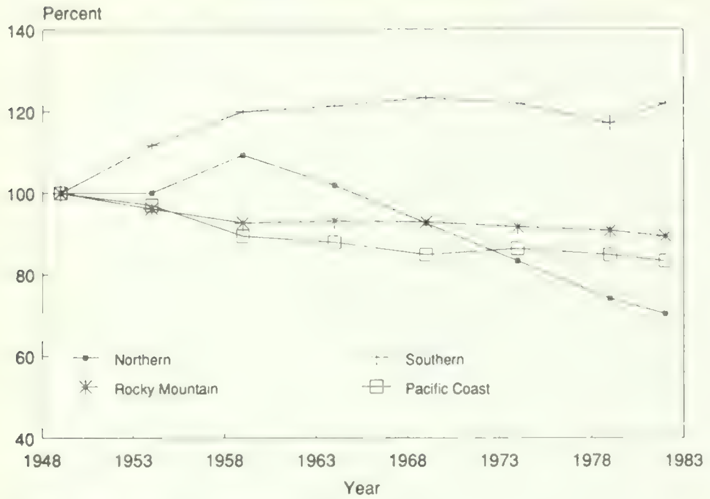
probably underestimate forest land available for grazing. The total amount of woodland pasture on farms has declined from nearly 140 million acres in 1950 to less than 50 million in 1982 (fig. 24), based on the Census of Agriculture statistics (USDC Bureau of Census 1984). Thus, the woodland available for grazing on farms has dramatically declined since 1950. As a percent of total woodland, the amount grazed has remained around 50% (USDC Bureau of Census 1984).

Regional Trends in Pasture and Rangeland Use

Conversions of pasture and rangeland varied regionally across the United States in 1949-82 (fig. 25). Conversions of pasture and rangeland to other land uses were greatest in the NO and PC regions with a 30% and 17% decline respectively, relative to 1949 acreage. These regions had the fewest acres of pasture and rangeland. The increase of pasture and rangeland in the SO region reflected a substantial reclassification of noncommercial forest to open rangeland in Oklahoma and Texas, a decline in cropland used for crops with the associated increase in cropland used for pasture, and the clearing of commercial forest land, particularly in South Carolina, Georgia, Florida, Alabama, Oklahoma, and Texas. This increase in the South was not large enough to compensate at the national level for decreases in other regions, notably in the Rocky Mountain region where areas were withdrawn for parks, wilderness, or reclassified as unsuitable for grazing (Frey and Hexem 1985).

Increased conversions of rangeland during the late 1970s were related to a variety of factors: (1) a depressed cattle industry contrasted with a profitable wheat sector encouraged the diversification of ranching operations to include wheat production (Wight et al. 1983, Young

[6]Frey and Hexem (1985) reported 890 million acres in 1969 and 820 million acres in 1982 of grazingland—forest, pasture, and range. This 70 million acres loss represents an annual loss of 0.6% per year, or 5.3 million acres per year from the grazingland base. When only pasture and rangeland acres are examined, 692 million acres in 1969 and 662 million in 1982, the annual loss is 0.33% or 2.3 million acres per year. When the declines in forest grazing are included with pasture and rangeland, the annual decline in grazingland area would represent a total decline of 53 million acres in the grazingland base over 10 years. Forest grazing, however, has declined for a number of reasons, including changing management practices which exclude livestock grazing. Thus, while the CRP land will return acres to forest land, changes in management on forest land could impact forest grazing much more significantly.



NOTE.--Data based on periodic inventories. Most recent inventory: 1982.

Source: Frey and Hexem (1985)

Figure 25.—Trends in pasture and rangeland area, relative to 1949, by assessment regions in the United States.

1984); (2) cash-flow problems encouraged ranchers to sell all or part of their land (Huszar and Young 1984); (3) increased credit availability on cropland as opposed to rangeland, and pressures from lending institutions to convert rangeland to cropland (Huszar and Young 1984, Young 1984); (4) price differentials in the market price of rangeland and cropland (Roath 1983, Watts et al. 1983); (5) incentives from government farm programs and income tax provisions that enhance the profitability of conversions (Heimlich 1985, Watts et al. 1983); (6) new technological improvements suggesting that semi-arid lands could be profitably cropped (Hendricks 1983); and (7) imperfect knowledge about climatic conditions in the arid regions suggesting to prospective buyers a possibility for farming (Laycock 1983).

Based on Frey and Hexem (1985), annual conversions of pasture and rangeland to other uses for 1969-82 period were:

Region	**Annual Conversion** million acres/year
Pacific Coast	0.08
Southern	0.15
Northern	0.92
Rocky Mountain	1.20

These annual rates can vary considerably with fluctuations in the demand for land for crop production. Schenarts (1981) reported that 31.9 million acres of pasture and rangeland alone were converted to cropland during 1967-75. Conversions of cropland to other uses, such as urban, exceeded the conversions into cropland over this period and the Nation's total cropland acreage decreased. The annual conversion of pasture and rangeland to cropland during 1967-75 was 0.2 million acres for the Pacific Coast region (2.5 times the 1969-82 rate), 1.2 million acres for the Southern region (8 times the 1969-82 rate), 1.1 million acres for the Northern region (1.2 times the 1969-82 rate), and 1.4 million acres for the Rocky Mountain region (1.2 times the 1969-82 period).[7] The conversion of pasture and rangeland to urban land use and the return of cropland to pasture and rangeland are not included in these conversion rates. These higher conversion rates indicate a greater loss of pasture and rangeland when cropland demand is high, as it was during 1967-75.

Concern about the recent plowing of fragile rangelands has provided several additional estimates of the historical rangeland conversion to cropland in the Great Plains. Laycock (1983) presented estimates of grassland acres plowed in the northern and central Great Plains (table 14). For the seven states represented, an estimated 0.41 million acres of rangeland were converted to cropland annually in 1967-83 (table 14). Again, this represents rangeland plowed only for conversion to cropland. Frey (1983) reported that historic levels of land cropped in the Great Plains were greater than cropland currently in production, 132.5 million acres versus the 91 million acres in 1978. Cropping was extensive in most Great Plains counties in 1919-29 and 1944-54. Frey (1983) suggested that if acreage control programs had not been in effect, more counties would have had record acres in crop production during the 1970s. Thus, the conversion of rangeland to cropland has been high during periods of high crop demand, and in some local areas, the rate of conversion is quite high (table 14). Heimlich (1985) reported that conversions of pasture and rangeland during 1975-81 accounted for between 64% and 84% of new cropland in all regions of the United States. Thus, range and pasture serve as a reservoir for new cropland in all parts of the country.

Table 14.—Rangeland plowed in the northern and central Great Plains States.

State	Acres plowed	Time period	Source
Colorado	572,000	1978-83	SCS
Kansas	15,000	1978-83	SCS
Montana	762,000	1970-83	Montana ACD[1]
Nebraska	400,000	1978-83	SCS
North Dakota	849,000	1967-83	SCS
South Dakota	759,000	1974-82	SCS
Wyoming	33,000	1977-83	SCS (Laramie Co.)

[1]Montana Association of Conservation Districts, available from 22 of 59 Soil Conservation Districts and do not include Phillips, Custer, and Garfield districts where plowing occurred in 1982-83.
Source: Laycock (1983).

[7]Conversion of pasture and range to cropland during 1967-75 totaled 1.7 million acres for the PC region, 10.0 million acres for the SO region, 8.6 million acres for the NO region, and 11.6 million acres for the RM region. For this 8 year period, annual conversion rates are 0.2 million acres, 1.2 million acres, 1.1 million, and 1.4 million acres, respectively.

Government Agricultural Programs and Land Use Shifts

Programs designed to reduce crop surpluses have been short-term where cropland was enrolled annually and long-term where cropland could be enrolled for up to 10 years. These programs affect the demand for cropland and consequently the rate at which rangeland is converted to cropland. Thus, consideration of current and future government agricultural programs is necessary to project future rangeland acres.

Recent concerns that the Dust Bowl lessons were being relearned in the conversion of highly erodible pasture and rangeland led to legislation at county, state (Lacey 1983, Roath 1983), and national levels (Food Security Act of 1985) restricting the plowing of fragile rangelands. The Food Security Act of 1985 included several subtitles aimed at reducing crop surpluses and environmental damages associated with cropland use. The objective of the Conservation Reserve subtitle was to provide a monetary incentive to remove highly erodible cropland from production. This incentive program is referred to as the Conservation Reserve Program (CRP). The objective of the Highly Erodible Land Conservation subtitle was to remove highly erodible cropland from production as a requirement for continued eligibility for commodity program benefits. The latter subtitle contains a "sodbuster" provision wherein the plowing of highly erodible land that is not currently cropped would cause the operator to become ineligible for price-support payments, farm storage facility loans, crop insurance, and disaster payments. A similar provision called "swampbuster" restricts the plowing of wetlands. The Highly Erodible Land Conservation subtitle also contains a conservation compliance provision wherein future commodity program benefits are denied to producers who do not have specific conservation plans on highly erodible cropland now in production. These provisions were intended to take highly erodible land out of crop production, reduce erosion levels on highly erodible land, and to stem the tide of highly erodible land conversion to cropland.

The CRP is scheduled to retire at least 40 million acres of cropland by 1990. Enrollment, as of mid-1987, was 22.9 million acres. Once a farmer's bid is accepted into the program, a permanent vegetation cover must be established on the acres enrolled and the vegetation cannot be commercially harvested or grazed by livestock for the duration of the 10-year contract, except where the Secretary of Agriculture permits, as in a drought or similar emergency (Dicks et al. 1987), as occurred in the summer of 1988. The land can be used profitably for wildlife grazing through hunting or recreation. Although most acres are being planted with a permanent cover crop of either tame or native grass, over 1.2 million acres have been accepted for tree plantings, mostly in the SO region (USDA Agricultural Stabilization and Conservation Service 1987).

Enrollment in the CRP as of the fifth sign-up in mid-1987 was largest in the Northern Rocky Mountain (NR) region and least in the California (CA) region (fig. 26).

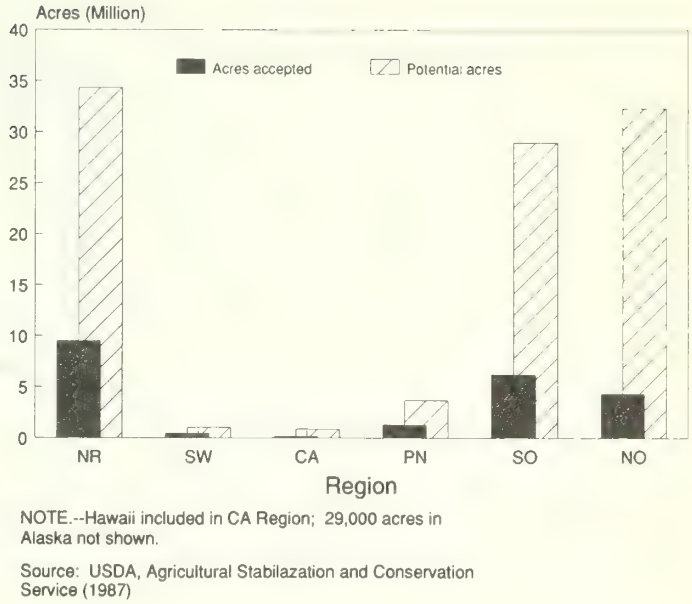


Figure 26.—Conservation reserve program as of the fifth signup (August 1987).

Each of the states of Colorado, Kansas, Montana, North Dakota (NR region), Iowa, Minnesota, Missouri (NO region), and Texas (SO region) have over a million acres enrolled. The national average size of the contract is 110 acres, although the size varies by region (USDA Agricultural Stabilization and Conservation Service 1987). If the regional contributions remained the same as shown in figure 26, then doubling these acres gives an indication of the likely regional distribution of enrolled acres when the national cap of 45 million acres is reached.

Heimlich (1985) suggested that the conditions favorable to land conversion during 1975-81 are not likely to reoccur in the immediate future. Hexem and Krupa (1987) mentioned factors that may discourage future cropland conversions: (1) less favorable cost/price relationships since 1981, (2) the Food Security Act of 1985, (3) changes in the federal tax code eliminating investment tax credits, capital gains exclusions, and the alteration of land development cost deductions. All regions have land that could potentially be placed in crop production (table 15). The largest areas of land with high potential for conversion occur in North and South Dakota, Nebraska, Kansas, Iowa, Missouri, Indiana, Illinois, Ohio, Oklahoma, and Texas. Seventy-six percent of the national acreage with high potential for conversion to cropland is currently in pasture and rangeland (Hexem and Krupa 1987).

LAND USE CHANGES AND RESOURCE MANAGEMENT: A REGIONAL CASE STUDY

Past assessments of natural resources have relied on a limited application of analytical approaches to project

Table 15.—Regional acreage (1,000 acres) with high and medium potential for conversion to cropland, 1982.

Region	Pasture and rangeland			Forestland		
	High	Medium	Total	High	Medium	Total
Northern	7,066	13,988	21,054	2,324	11,467	13,791
Southern	11,476	34,902	46,378	4,701	20,002	24,702
Rocky Mountain	7,317	28,406	35,723	82	429	511
Pacific Coast	1,165	3,715	4,880	144	1,837	1,981

Source: Table 5 from Hexem and Krupa (1987).

resource supplies and inventories. These assessments have been criticized for not analyzing future resource production in a multiple resource context (Schweitzer et al. 1981). In response to such criticism, Joyce et al. (1986) developed a regional modeling framework that analyzed multiple resource response to land management activities. The SO region of the United States was chosen as the test area for the application of this framework. This study, the first of its kind at the regional level, represents a prototype of how future national assessments may address regional multiple resource production.

Modeling Approach

Four distinct but closely related systems of models were linked in a multiresource framework (Joyce et al. 1986). The Timber Assessment Market Model (TAMM) estimated the future demand for wood products and the roundwood harvest needed to meet this demand (Adams and Haynes 1980). The Timber Resource Inventory Model (TRIM) projected changes in timber inventory, growth, and harvest on timber stands defined by ownership, timber management type (natural pine, planted pine, oak-pine, upland hardwoods, and bottomland hardwoods), and site class (Tedder et al. 1987). Changes in major land uses (forest, pasture/rangeland, cropland, and human-related land), timber management type conversions, and ownership were simulated with the Southern Acreage Model (Alig 1985). The impact of land area and timber management changes on the southern landscape were simulated by using resource models for white-tailed deer, wild turkey, and red-cockaded woodpecker (Flather et al. 1989), trout (Flebbe et al. 1988), water quantity (Sisler 1986), and forage (Joyce in prep.). A summary of the results for all resources is presented in USDA Forest Service (1988d). The results of the forage analysis will be presented here.

Forage Production Models

The objective of the forage component of this study was to develop production estimates based on land use, timber stand descriptions, timber management activities, and environmental characteristics. The forage model projects forage production on pasture, range, and forest land by using environmental and management factors specific to each land type (Joyce 1988, in prep.). This study included all states in the SO region (fig. 1) except Kentucky and the western parts of Oklahoma and Texas. The South Central subregion consisted of Alabama, Mississippi, Louisiana, Arkansas, Tennessee, and the eastern parts of Texas and Oklahoma. The Southeast subregion included Virginia, North and South Carolina, Georgia, and Florida.

The modeling approach for pasture and rangelands is patterned after Sharp et al. (1976) where rates of production specific to each land type were used to estimate, along with acres within each land type, the forage production at the state level. Range forage production rates were taken from the Range Site Descriptions developed by SCS personnel within each state. Pasture forage production rates were estimated by using hay production within each state (U.S. Department of Agriculture 1984). On forested stands, the modeling approach follows Joyce and Baker (1987) where forest overstory characteristics such as timber type and volume, management practices such as burning history, and environmental characteristics such as precipitation, were statistically related to forage production. Timber stand characteristics significantly associated with forage production varied by timber management type and age class (Joyce 1988).

Modeling the possible impacts of changing land use and timber management on forage production requires a number of assumptions. These assumptions reflect acknowledgment of factors influencing forage production that could not be quantified in the model. Specifically, it was assumed that forage production changes on forested lands over the projection period are the result of changes in forest stand characteristics. Consequently, environmental factors that influence understory vegetation (e.g., climate change) are assumed to remain similar to past and current values. Timber management practices are assumed not to change in a way that will affect forage production responses over the projection period. For example, planting practices in pine plantations are assumed not to change tree density and spacing in such a way as to increase light reaching the forest floor. Pasture management practices, such as fertilization, are assumed not to change in a way that will affect forage production. Incorporating these factors into a quantitative analysis of forage production at the regional level will require further research.

Results

A future scenario was developed to represent the likely demand for timber products and the level of timber management required to ensure that the timber supplies would meet that demand for 1985 to 2030. A set of assumptions concerning population growth, economic growth, and timber management were used to generate the timber and land area projections (USDA Forest Service 1988d). A panel of forestry experts from the South, including forest industry, state forestry, and federal agency personnel developed the assumptions concerning likely future timber management actions.

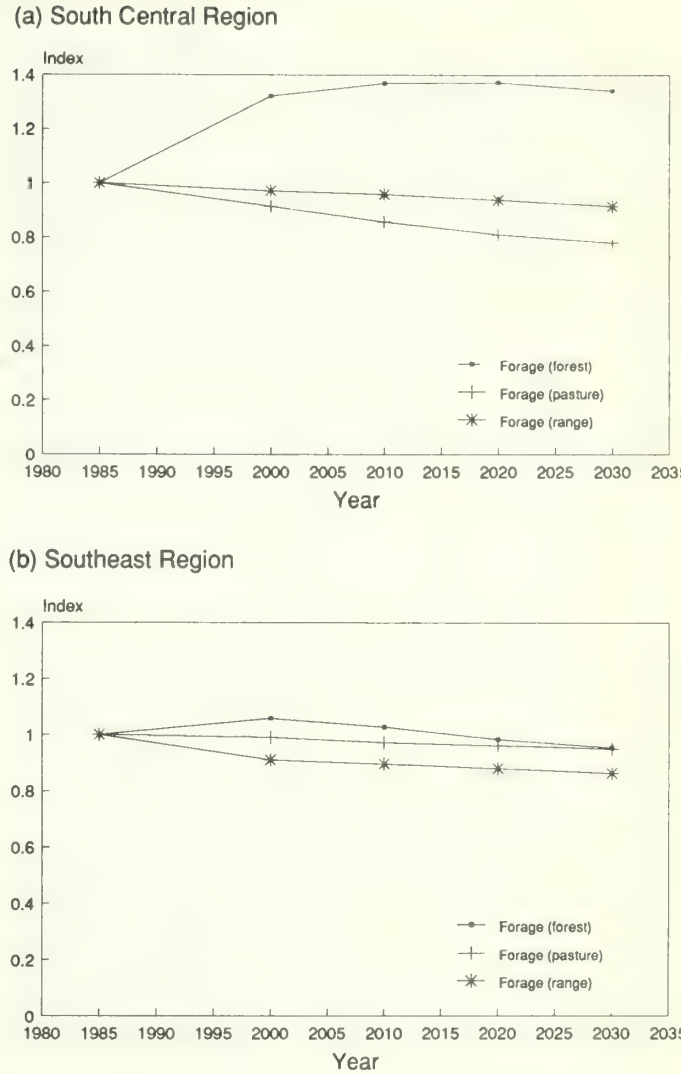
Under this future, land area shifts over the entire South were dominated by a reduction of forest land by 3% and an increase in human-related land by 50%. Pasture and rangeland acres declined 7 million acres, or 14% over the projection period for the entire South. Acres in planted pine increased substantially, from 5% of the southern landscape to nearly 15%. These acres come primarily from the conversion of natural pine, but acres of upland hardwoods and oak-pine are also converted to planted pine.

The total production of forage from all sources decreased over the projection period (fig. 27). The overall decrease reflected the southwide conversion of pasture and rangeland acres to other land uses. Forage production on forested stands increased as the older stands were harvested and regenerated, however, this increase did not compensate for the larger decreases in pasture and rangeland forage. Other factors that contributed to the increase in forest forage production included forest land conversion to planted pine types having a relatively more open canopy and management emphasis on reduction of brush.

Between 80% to 95% of the pasture in the South is currently grazed (USDA Soil Conservation Service 1987a). The results of this study suggest that if grazed roughage demands stay at their current level, forage on pasture and rangelands will be insufficient to meet the demand. Forest lands represent an extensive reservoir of grazed roughages as less than 10% are currently grazed (USDA Soil Conservation Service 1987a). The use of this forage reservoir to compensate for the decline in forages from pasture and rangelands will need to reverse an historical trend of decreased grazing on forested lands (Frey and Hexem 1985).

The extensive conversion to planted pine and the need to manage understory vegetation on these stands to reduce competition with the young seedlings suggests a future need for vegetation management (Pearson 1987). Increasing constraints on chemical control will necessitate alternative methods to manage this vegetation. The use of livestock as a biological vegetation control tool shows great potential in the South (Pearson 1987) as well as other places nationwide (Krueger 1987).

The results of this case study suggest methods to address multiresource interactions in national assessments. Resource models for timber, wildlife, forage, fish, and water were linked at the regional level for the first time. The importance of a consistently and completely defined land base was demonstrated in the linkages across these models. This analysis is an impact analysis that is entirely driven by the land use and the timber inventory projections. Traditionally, the use of land for grazing has been considered residual use, grazed when the land can be used for nothing else. Additional research is needed to adapt this methodology to other regions and to improve the feedbacks between resources during the projection period.



Source: Joyce (1988)

Figure 27.—Indexed response of resources—baseline scenario.

SUPPLY OF PUBLIC FORAGE

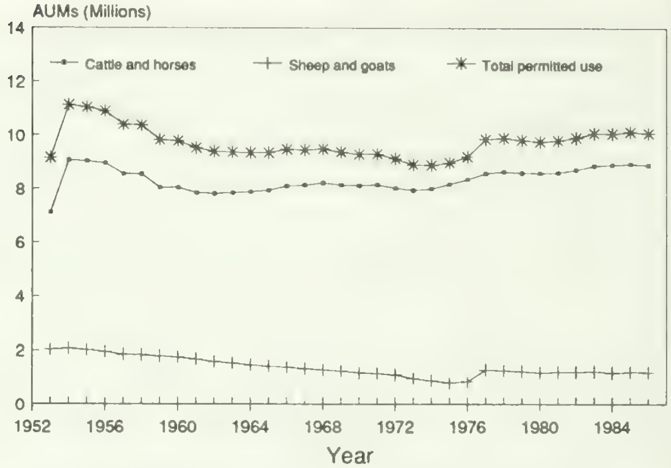
The supply of forage on public lands is reflected in the number of Animal Unit Months (AUMs) permitted to graze each year. Although these numbers are influenced by factors affecting the demand of forage on public lands, use of public grazing is an indication of the supply of forage.

National Level

Numerous federal, state, and local government agencies permit grazing on public lands. The largest suppliers of permitted grazing on federal lands are the FS with 10 million AUMs and the BLM with 12.5 million AUMs in 1986 (table 9). The 7 million AUMs that other western agencies permit is probably a minimum estimate, as only 113 out of 257 sites had AUM records (Bartlett et al. 1983). The Bureau of Indian Affairs was the largest supplier of grazing in their survey. More complete records indicate the Bureau of Indian Affairs supplies over 4.9 million AUMs of grazing (Kipp pers. comm). Other federal agencies reported by Bartlett et al. 1983 included National Park Service (81,752 AUMs), Fish and Wildlife Service (264,723 AUMs), U.S. Army (57,463 AUMs), U.S. Navy and Marines (23,632 AUMs), Agricultural Research Service (19,920 AUMs), U.S. Air Force (18,265 AUMs), Bureau of Reclamation (8,011 AUMs), and the U.S. Army Corp of Engineers (3,610 AUMs).

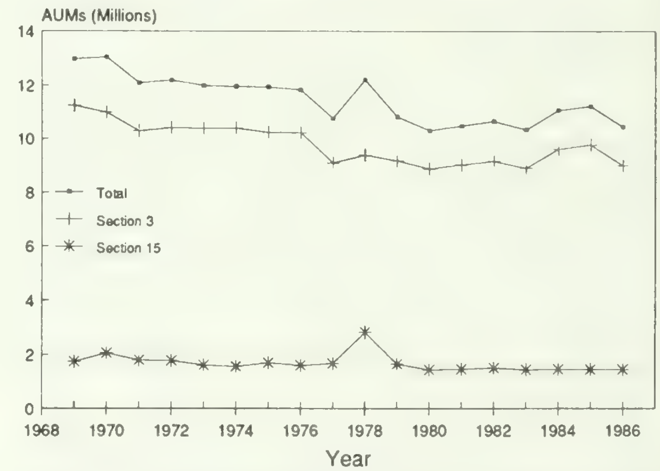
Historical records on NFS lands indicate that grazing has remained fairly constant since 1953 (fig. 28a). The increase in 1954 is the addition of National Grasslands to the Forest Service (table 13). The slight decline, less than 1 million AUMs, is the result of a decline in the number of sheep and goats grazing NFS lands. Reductions in cattle allotments have also occurred in some regions. Livestock grazing on BLM-administered lands[8] has declined as a result of reductions in stocking rates on some allotments and a transfer of BLM-administered lands to other agencies (USDI Bureau of Land Management 1984) (fig. 28b). Although a breakdown by animal type was not available for Section 15 lands[9] from BLM, trends on the Section 3 lands[10] indicate a similar decline in sheep as was seen on NFS lands.

(a) National Forest System lands



Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)

(b) Bureau of Land Management-administered lands



NOTE.--BLM AUMs were multiplied by 1.2 to compare with NFS.

Source: USDI, Bureau of Land Management (1969-1987)

Figure 28.—National grazing use.

Regional Supplies from Forest Service and Bureau of Land Management

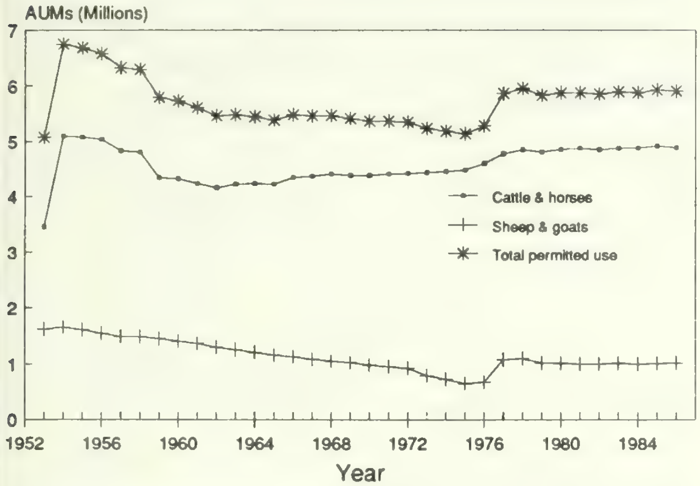
In the NR region, elevations of rangelands suitable for grazing vary from 800 feet in Kansas to over 12,000 feet on alpine ranges. Plant communities along this elevational gradient include sandhill prairies, sagebrush-grass, ponderosa pine and mountain bunch grass communities, aspen, mountain meadows, and alpine meadows (fig. 2). Although grazingland occurs on federal, state, and privately-owned land, livestock enterprises with their year-round cattle and sheep operations receive an essential component in their grazing balance from federal lands (USDA Forest Service 1981a). Paralleling the national trend, the number of AUMs permitted to graze on public lands in the NR region has declined in 1953-86 (figs. 28 and 29). The number of AUMs on NFS lands peaked at nearly 7 million in 1954 and has declined since then to about 6 million AUMs in 1985 (fig. 29a). The early rise in 1954 reflects the inclusion of National Grasslands into the NFS, increasing the AUMs available by nearly 2 million. Cattle grazing dominates NFS use in this region. Horse use in this region is mainly pack and saddle animals for camping, hunting, and fishing trips (USDA Forest Service 1981a, 1984b). Sheep AUMs in Utah and Nevada alone totaled nearly 1 million AUMs in the 1950s but have declined to near 750,000 in the 1980s.

[8]*To compare BLM AUMs with FS AUMs, multiple BLM AUMs by 1.2 (USDA Forest Service and USDI Burea of Land Management 1986).*

[9]*Section 15 lands on BLM are public lands administered by BLM outside of grazing districts in western states leased for grazing purposes under authority of Section 15 of the Taylor Grazing Act.*

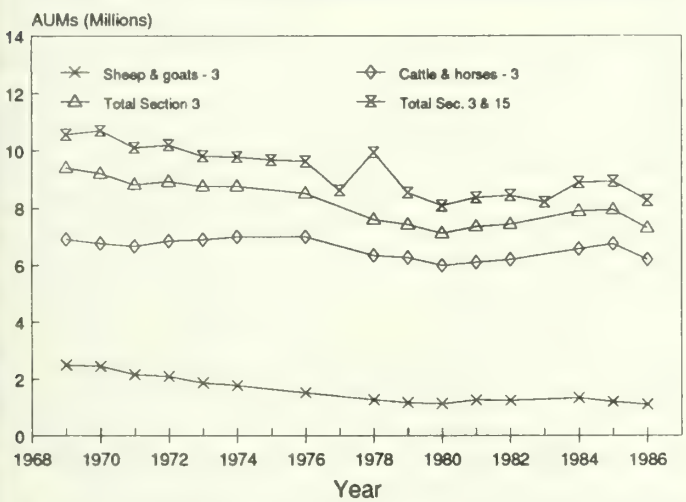
[10]*Section 3 lands are public lands within grazing districts administered by BLM in western states leased for grazing purposes under authority of Section 3 of the Taylor Grazing Act.*

(a) National Forest System lands



Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)

(b) Bureau of Land Management-administered lands

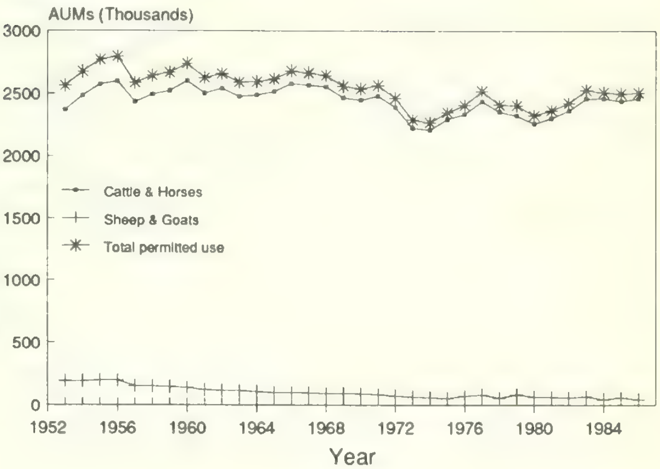


NOTE.—BLM AUMs were multiplied by 1.2 to compare with NFS.

Source: USDI, Bureau of Land Management (1969-1987)

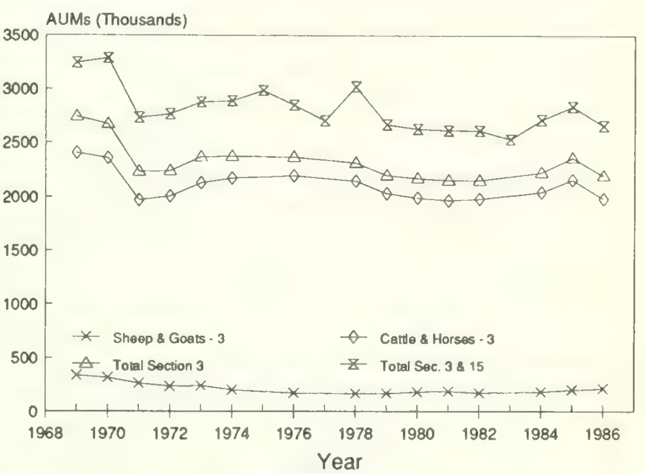
Figure 29.—Northern Rocky Mountain region grazing use.

(a) National Forest System lands



Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)

(b) Bureau of Land Management-administered lands



NOTE.—BLM AUMs were multiplied by 1.2 to compare with NFS.

Source: USDI, Bureau of Land Management (1969-1987)

Figure 30.—Southwest region grazing use.

The NR region accounts for nearly half of the national BLM AUMs. Data available from 1969 to 1986 indicate a decline from nearly 9 million AUMs permitted in 1969 to less than 8 million in 1986 (fig. 29b). Although a breakdown of sheep and cattle AUMs on Section 15 lands over time was not available, AUMs for cattle and sheep on BLM section 3 lands reflect the trends shown for NFS lands within this region (fig. 29). Sheep use has declined nearly 50%, resulting in 1 million fewer AUMs for sheep on BLM lands by 1986.

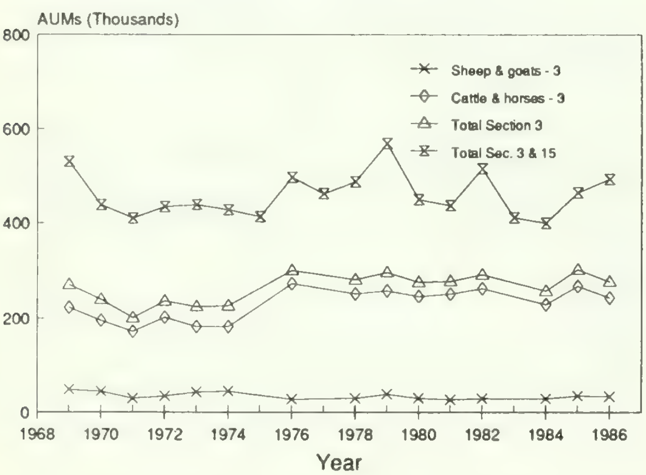
In the Southwest (SW) region, 85% of the land under all ownerships is rangeland and livestock grazing is estimated to occur on 90% of this land. Grassland, woodland, and forest ecosystems comprise the suitable grazinglands; 46% occurs in woodland ecosystems. About 45% of the NFS permittees graze livestock yearlong on NFS lands (USDA Forest Service 1983a). Cattle comprise the major use of NFS grazing in this region. Permitted AUMs on NFS lands in the SW region have fluctuated around 2.5 million since the late 1950s (fig. 30a), even though regionally, cattle inventories increased 66% in the early parts of this period. Sheep and goat use on NFS lands has declined since 1953. Permitted grazing on BLM lands in the Southwest has declined from over 3.2 million AUMs in 1969 to less than 3 million in 1986 (fig. 30b). As on NFS lands, cattle comprise the major use and sheep and goat use have declined.

In the CA region, grazing patterns differ for the two agencies. Permitted AUMs were higher in California on NFS lands in 1984 than in 1953 (fig. 31a). The rise in total AUMs on public lands lags the rise in cattle numbers. As a percentage of the total AUMs, cattle grazing is the primary use of NFS grazinglands. Permitted sheep use

(a) National Forest System lands

Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)

(b) Bureau of Land Management-administered lands



NOTE.—BLM AUMs were multiplied by 1.2 to compare with NFS.

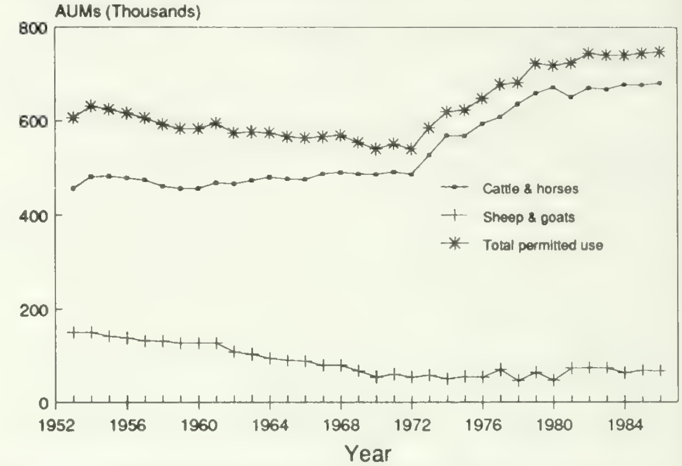
Source: USDI, Bureau of Land Management (1969-1987)

Figure 31.—California region grazing use.

has declined on NFS lands. Use on BLM lands in California is the smallest for all western regions. Total permitted grazing since 1969 has fluctuated greatly, largely because of ephemeral precipitation in the southern part of this region (fig. 31b). On Section 3 lands, sheep and goat AUMs have remained fairly constant, but cattle AUMs have continually increased over the period (fig. 31b).

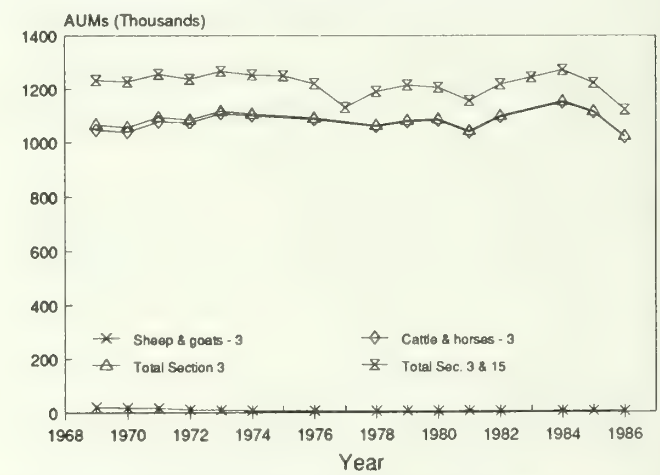
As in other western regions, grazing on public lands in the Pacific North (PN) region is important in completing the year-long feed mix within livestock enterprises. More than 80% of the grazing lands on NFS lands are forested (USDA Forest Service 1984c). Unlike trends seen in other regions, AUMs on public lands in the PN region have either increased (NFS lands) or fluctuated slightly around the same number since 1969 (BLM lands) (fig. 32). Permitted AUMs on NFS lands have increased since 1953, the result of a nearly 30% increase in cattle AUMs. Permitted sheep use has declined substantially, paralleling

(a) National Forest System lands



Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)

(b) Bureau of Land Management-administered lands



NOTE.—BLM AUMs were multiplied by 1.2 to compare with NFS.

Source: USDI, Bureau of Land Management (1969-1987)

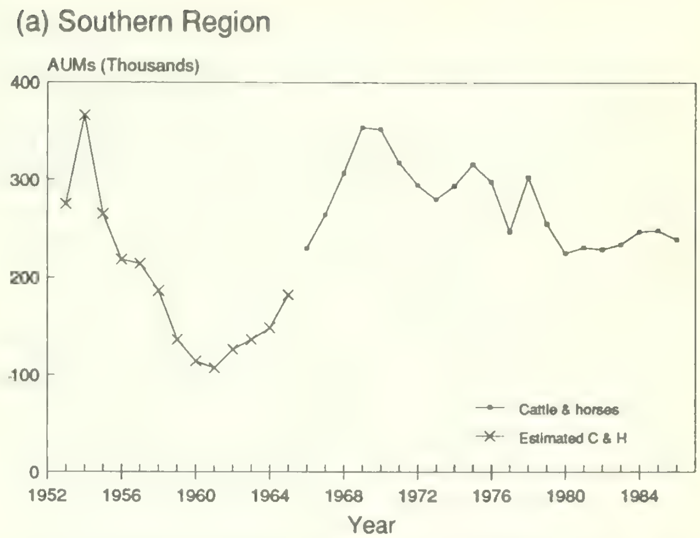
Figure 32.—Pacific North region grazing use.

the regional decrease in sheep numbers. Actual use on BLM lands has remained fairly constant since 1969 (fig. 32b). Cattle AUMs on Section 3 lands have remained fairly constant while sheep AUMs, which were a small component of BLM grazing have declined since 1969.

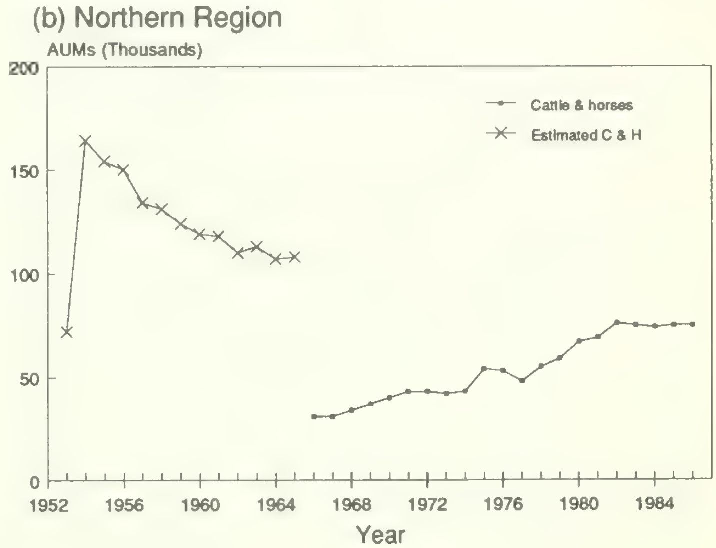
Only 12.5 million acres, or 3.9% of the total acres, of forest and rangeland in the SO region are on NFS lands. Of these lands, only 2 million acres are considered suitable for grazing. Thus, NFS permitted AUMs in the SO region are the lowest of all regions (fig. 33a). Only 38,000 acres of NFS lands are in vegetation types such as grassland, prairie, wet grassland, and savannah (USDA Forest Service 1984d). More grazing opportunities on southern national forests occur in regeneration areas and openings within longleaf pine and loblolly-shortleaf pine ecosystems. Although these permitted numbers represent an estimate of supply, it is important to note that additional grazing opportunities could be provided

on southern national forest lands (USDA Forest Service 1984d). The decline or break in the historical trends in the SO and NO regions is the result of grazing management operations shifting to a grazing permit system in the mid-1960s (Rowley 1986). Before this point, only approximate estimates of the grazing on these forests are available.

Although NFS lands comprise over 6 million acres in the NO region, only 880 thousand acres (14%) is considered to be suitable for livestock grazing (USDA Forest Service 1981b). As in the South, grazing opportunities are primarily forest openings or regeneration sites. Grazing on NFS lands in the NO region declined between 1953 and 1965 (fig. 33b). Cattle grazing, either dairy or beef, dominates the grazing use in this region. Sheep use is very small (3,000 AUMs). The BLM does not administer any grazing within the NO or SO regions.



Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)



NOTE.—Sheep use is about 3,000 AUMs

Source: USDA, Forest Service (1978-1987a); USDA, Forest Service (1986b)

Figure 33.—Grazing use on eastern National Forest System lands.

SUMMARY

Forage, that part of vegetation that is available for consumption by wild and domestic herbivores, is produced on forest land, rangeland, pasture, hayland, cropland (after crop harvest), and cropland used for pasture. Management results are influenced by the ecology of forest and range ecosystems. Past and current uses such as grazing, timber harvesting, mining, cropping and abandonment of cropland, and species introduction, have and will continue to have an affect on production from these lands. New technology, and eventually biotechnology, offers possibilities to enhance the future productivity of forest and rangelands. Economic factors, however, affect the implementation of range management technology, and the highest implementation rates have occurred for practices requiring minimal capital investment.

The management of forest and rangelands, government agricultural programs, and the environment interact to influence changes in land use across the United States. The availability of land for forage production for wild or domestic herbivores is a function of the demand for land for other uses. Conversion of forest and rangeland to a nonrevertible use such as urbanland decreases the land available for forage production and for wildlife habitat. Crop prices, the demand for cropland, government programs aimed at reducing crop surpluses, and variation in acres of crops planted influence the amount of forage supplied by cropland, the conversion of rangeland to cropland, and the price of rangeland. At times, conversion of rangeland to cropland has been high, prompting legislation to regulate the flow of highly erodible land into crop production. Conditions favorable for rangeland and forest land conversion to cropland are not likely to reoccur in the immediate future because of the following factors: (1) less favorable cost/price relationships, (2) Food Security Act of 1985, and (3) changes in the federal tax code.

The supply of forage from public lands is set by multiple resource management objectives and public policy. Recent legislation has emphasized the multiple use of federal lands, the need to examine potential impacts of management, the management of wild horses and burros, and resource planning on federal lands. Thus, the quantity of forage produced on public lands will be a function of multiresource management for wild and domestic grazing animals such as livestock, wildlife, and wild horses and burros, and other resource outputs such as timber, water, recreation, and scenic beauty. Multiresource management requires a consideration of the tradeoffs in resource production.

Assessing the forage produced nationally is difficult because forage production is not inventoried. Use, not production, is quantified when forage consumption estimates are derived from herbivore inventories. Projections of forage production will be derived from projections of the likely future technological improvements in forage production, and projections of land available for forage production. These projections, based on factors discussed here, are presented in Chapter 4.

CHAPTER 3: FACTORS AFFECTING THE DEMAND FOR RANGE FORAGE

INTRODUCTION

Demand is defined as the quantity of product willingly bought per unit of time at a specific price[11] (Workman 1986). Less than 10% of forage consumed by livestock is leased or sold in an observable market (table 10). The price of forage from Forest Service (FS) land and on Bureau of Land Management (BLM) administered land is set by federal law. The price for forage from private lands is not usually determined by competitive bidding within a market system because this forage is often produced within the farm or ranch enterprise. Forage for wild herbivores is not usually priced in a market. Without an observable market for most of the forage consumed, the national demand for forage is difficult to analyze in terms of the traditional supply/demand equilibrium analysis of commodities as described for beef by Workman (1986).

Forage produced on forest and rangelands is intermediate to the production of the final output, such as wildlife, livestock, wild horses and burros (Bartlett 1986). The demand for the final output, the herbivore, can be used to derive the future demand for range forage. Forest and rangelands also provide other commodity outputs and noncommodity outputs (chapter 1). The management of forest and rangelands must be responsive to the demand for forage and the demand for other range outputs. Research is needed to determine the value of range vegetation in the production of these outputs (Bartlett 1986), and to develop a method for allocating the range resource across these demands (Broken and McCarl 1984).

The present chapter addresses the factors that affect the demand of range forage as derived from the demand for domestic herbivores. The demand for livestock is a function of society's demand for market commodities such as meat, hides, wool, tallow, and secondary products such as pharmaceuticals (Council for Agricultural Science and Technology 1986, USDA Forest Service 1980). About 78% of the gross income from sheep and lamb is attributed to meat, primarily lamb, with the remaining income from the sale of wool. In 1982, 73% of the cash receipts from the sale of all meat animals were from marketing cattle and calves (Nelson 1984).

Forage demand for livestock production depends on the technology associated with livestock production, the prices of alternative feeds, the total feed mix, and the price of livestock. The price of beef cattle or sheep depends upon the interactions between the supply and the demand of meat. The supply of meat is determined by the cost structure of production. The demand for meat is a function of export demand and domestic consumption. The demand for beef or lamb meat is related to consumer tastes and preferences, disposable income, changes in human population size and age distribution, and the relative prices of alternative foods, particularly other meats.

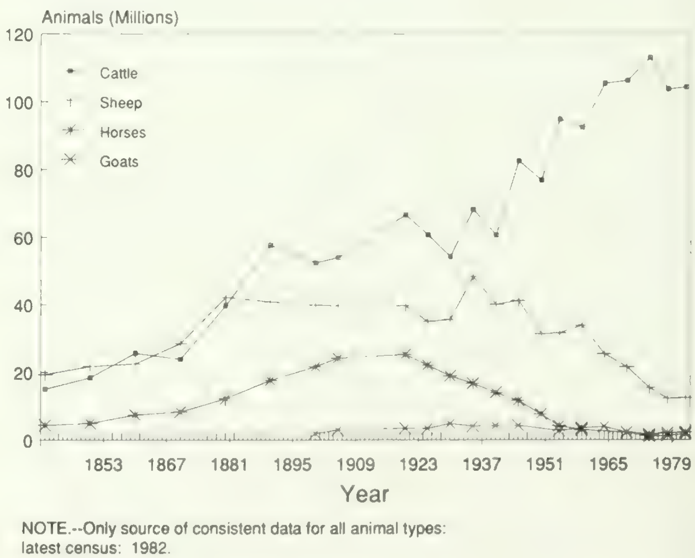
The demand for wild herbivores is a function of society's demand for nonconsumptive recreation, such as nature walks, and consumptive recreation such as hunting. Society's desire for recreational experiences associated with wild herbivores has increased the value of these grazing animals. Meeting the forage requirements of livestock and wildlife is an important management objective on public and private lands. Projections of the future demand for wild herbivores, made by Flather and Hoekstra (in press), are compared with this report's projections for domestic herbivores in Chapter 5.

[11] *This assumes all other prices, population, income, tastes, preferences, and any other factors that might affect quantity demanded are held constant.*

LIVESTOCK PRODUCTION IN THE UNITED STATES

Historical Livestock Numbers at the National Level

Cattle and sheep inventories were nearly equal in 1840 and both animal types increased until 1880 when sheep inventories leveled off (fig. 34). Cattle numbers continued to increase until 1975 when inventories reached



NOTE.--Only source of consistent data for all animal types: latest census: 1982.

Source: USDC, Bureau of Census (1935-1982)

Figure 34.—Number of livestock on farms in the United States.

their historical peak and began to decline. Sheep numbers peaked in the mid-1930s at about 56 million head and have since dropped to 10 million head in 1986 (USDA 1987). Horse numbers increased with the westward expansion of agriculture to a peak of 20 million in the 1920s. At this time the tractor was introduced, and mechanical power gradually replaced horses. In 1982, horse inventories were around 2 million animals on farms, or 5 million if the growing numbers of recreational animals are included. Goat inventories have historically been small compared with other grazing animals (fig. 34). In 1984, about 1.5 million goats were reported in the United States, mostly in Texas (USDA Statistical Reporting Service 1985).

Historical Livestock Numbers at the Regional Level

Cattle numbers in western regions increased from 17% to 35% over 1955 numbers (table 16). Sheep numbers dropped to levels ranging from 37% to 51% of the 1955 inventories. In the Northern Rocky Mountain (NR) region, cattle numbers rose continually until they peaked in 1974 at 34 million (table 16). By 1986, cattle numbers were at only 79% of the 1974 peak but 117% of the 1955 level. Sheep inventories rose to 11 million animals in 1959 and declined thereafter. By 1986, sheep numbers were 34% of the 1955 inventory in the NR region. In the Southwest (SW) region, cattle numbers increased nearly 66% between 1955 and 1973 to 3.0 million, and then declined to 2.4 million by 1986 (table 16). Southwestern sheep numbers have declined since 1955 and in 1986 were less than 50% of the 1955 inventory. Cattle inventories within the California (CA) region have sustained the greatest increase of all western regions, 138% of the 1955 inventory in 1986 (table 16). Sheep numbers have followed the national trend. Cattle numbers in the Pacific North (PN) region have increased since 1955; sustained declines occurring only since 1980. Sheep numbers in the PN region have paralleled the national trend.

Cattle numbers in the eastern regions (Northern and Southern) rose only 4% from 1955 to 1986, whereas sheep numbers declined 75% (table 17). In contrast to national increases between 1955 and 1974, cattle numbers in the Northern (NO) region remained fairly constant, a reflection of this region's dairy industry. After

Table 16.—Livestock numbers (1,000 head) in the western United States by assessment region.

Year	Northern Rocky		Southwest		California		Pacific North	
	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
1955	22,927	9,904	2,147	1,627	3,863	1,700	2,646	1,105
1956	23,158	9,912	2,234	1,581	3,863	1,700	2,674	1,075
1957	21,346	9,906	2,087	1,587	3,870	1,632	2,520	1,080
1958	21,887	10,827	1,999	1,591	3,733	1,616	2,545	1,095
1959	23,071	11,103	2,133	1,647	4,044	1,600	2,675	1,146
1960	24,144	10,742	2,377	1,743	4,274	1,712	2,824	1,185
1961	23,071	10,440	2,221	1,606	4,207	1,763	2,643	1,150
1962	23,796	10,157	2,262	1,583	4,232	1,657	2,703	1,082
1963	25,631	10,190	2,339	1,550	4,778	1,541	2,835	1,004
1964	27,234	9,850	2,341	1,515	4,902	1,526	2,963	953
1965	27,397	9,344	2,246	1,420	4,913	1,511	3,054	859
1966	28,122	9,173	2,244	1,434	5,022	1,511	2,917	838
1967	28,729	9,292	2,489	1,315	5,119	1,412	2,947	667
1968	28,837	8,336	2,506	1,237	5,168	1,370	2,931	632
1969	29,007	7,849	2,552	1,227	5,140	1,234	2,863	613
1970	29,733	7,518	2,688	1,215	5,107	1,185	2,853	574
1971	31,036	7,252	2,661	1,192	5,020	1,149	2,894	544
1972	31,954	7,066	2,804	1,122	4,907	1,011	2,891	530
1973	32,477	6,681	3,035	1,084	4,952	956	2,903	491
1974	34,281	6,349	3,005	1,057	5,490	980	2,850	477
1975	32,997	5,626	2,890	930	5,450	910	2,890	432
1976	31,313	5,028	2,930	927	5,245	870	2,875	402
1977	29,675	4,483	2,565	910	4,990	900	2,870	374
1978	28,919	4,270	2,685	924	4,664	915	2,765	366
1979	28,634	4,162	2,700	935	4,915	965	2,850	406
1980	28,865	4,021	2,650	935	4,763	1,000	3,154	435
1981	29,905	4,178	2,475	920	4,980	1,030	3,200	500
1982	29,935	4,536	2,500	915	5,228	1,010	3,380	543
1983	30,165	4,526	2,450	858	5,130	920	3,220	450
1984	30,340	4,041	2,370	786	5,226	900	3,360	412
1985	28,695	3,962	2,460	718	5,181	870	3,120	398
1986	26,975	3,459	2,440	686	5,209	860	3,035	383

Source: U.S. Department of Agriculture (1955-1987), Agricultural Statistics.

Table 17.—Livestock numbers (1,000 head) in the eastern United States by assessment region.

Year	Northern		Southern	
	Cattle	Sheep	Cattle	Sheep
1955	35,646	5,778	29,363	7,114
1956	36,079	5,832	29,457	6,871
1957	36,013	5,919	28,666	6,414
1958	35,371	6,204	28,432	6,670
1959	35,482	6,198	29,245	7,135
1960	36,715	6,146	31,186	7,688
1961	35,405	5,689	29,772	7,469
1962	36,013	5,535	30,494	6,961
1963	36,549	4,945	31,596	6,485
1964	36,589	4,553	32,451	6,118
1965	36,765	4,558	32,801	5,549
1966	35,340	4,264	32,884	5,874
1967	35,084	3,722	34,269	5,263
1968	34,545	3,501	34,817	4,595
1969	34,491	3,378	35,823	4,347
1970	34,784	3,249	37,129	3,932
1971	34,918	3,092	37,932	3,988
1972	35,643	2,678	39,654	3,560
1973	35,961	2,522	42,197	3,278
1974	37,180	2,271	44,855	3,193
1975	38,278	2,023	49,312	2,904
1976	38,360	1,800	47,248	2,804
1977	37,172	1,899	45,530	2,676
1978	35,574	1,765	41,760	2,637
1979	33,611	1,766	38,145	2,545
1980	33,807	1,798	37,945	2,540
1981	34,533	1,847	39,220	2,446
1982	34,492	1,958	40,060	2,613
1983	33,780	1,688	40,445	2,347
1984	32,646	1,584	39,949	2,056
1985	31,655	1,485	38,598	1,914
1986	30,425	1,405	37,375	1,939

Source: U.S. Department of Agriculture (1955-1987), Agricultural Statistics. NOTE: Oklahoma and Texas are included in the Southern region.

1976, however, cattle numbers followed the national decline, dropping from 38 million to 30 million in 1986. Sheep numbers in the NO region also reflected the national trend. In 1955, cattle numbers in the Southern (SO) region were only 82% of cattle inventories in the NO region (table 17). By 1986, cattle inventories were greater in the South than the North. A continuous decline in southern sheep inventories has occurred since 1955 (table 17).

The largest inventories of cattle are in the NR region, the NO region, and the SO region (tables 16 and 17). The 17 western states support more than 80% of the Nation's sheep inventory (Council for Agricultural Science and Technology 1982). About 20% of the nation's sheep herd is in Texas. Large sheep inventories are also in California, Wyoming, South Dakota, Utah, New Mexico, Montana, and Colorado. Between 1960 and 1982, sheep production in the western regions rose from 75% to 82% of the national total. This shift from east to west may be related to the conversion of pasture land to crop production in the east and a trend toward agricultural specialization (Gee and Madsen 1988).

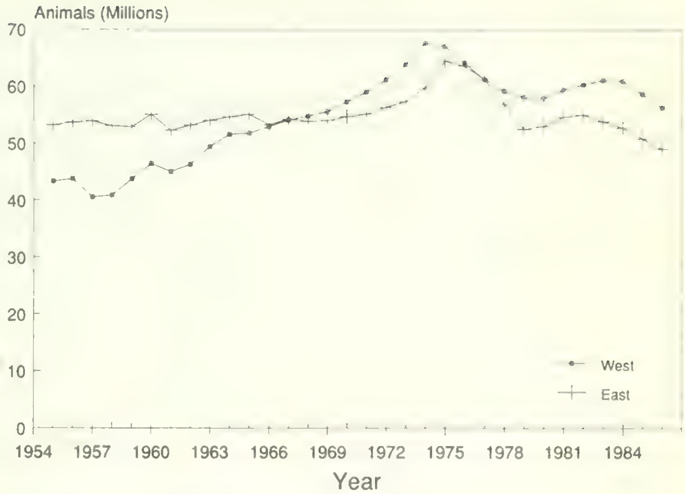
Cattle Cycles

Cycles in cattle inventories are initiated when producers, responding to rising economic indicators such as cattle prices, build up their herds. Because producers must wait nearly 3 years from the time a heifer is bred until its calf is old enough to enter the breeding herd (Gilliam 1984), the expansion part of the cycle (cattle numbers increasing) lasts from 5 to 6 years. Forage demands increase during this part of the cattle cycle. With greater cattle supply, prices begin to decline, and the producers begin to liquidate their herds until supply is low and prices begin to rise. The cycle commences again.

The last two cycles, starting in 1967 and in 1980, have not followed the dynamics of previous cycles (Gustafson 1983). Cattle numbers in the 1967-79 cycle peaked in 1975 at over 130 million head. By 1979, cattle numbers had dropped 21 million head, a 16% decline. Herd expansion in the next cycle added only 4.6 million head to the national inventory. Unlike previous cycles, this expansion did not increase the national herd over historic levels (fig. 34). Inventory on January 1, 1987 was 102 million head, 21% lower than 1975 levels.

These recent aberrations in the cattle cycle may be the result of several factors. The rise during the 1967-79 cycle reflected an expanding forage base from highly productive cropland shifting to cropland pasture and increased use of cheap fertilizer (Gustafson 1983). The rapid cattle decline coincided with rising grain prices, rising energy prices, and land shifting back into crop production. Herd expansion during the 1980 cycle was small, reflecting the agricultural financial crisis, and record high total meat supplies (Gustafson 1983). Bobst and Davis (1987) estimated that each million acre addition in harvested cropland (cropland expansion implied a decrease in pasture) was associated with a decline of nearly 37,000 beef cows.

In terms of forage supplies, the dynamics of these cattle numbers give an indication of the forage potential within the cattle production system. Eastern livestock operations are more closely associated with crop production than livestock operations in western United States (Gilliam 1984). Thus, the changes in land used for crops in the eastern United States will impact the forage available for grazing animals. A comparison of livestock numbers in the West (all western assessment regions plus Oklahoma and Texas), and in the East (NO and SO regions minus Oklahoma and Texas) indicates a shift of livestock production from eastern to western regions over 1955-86 (fig. 35). Livestock production in the West expanded much more rapidly than in the East. National cattle numbers have declined 21% between 1975 and 1986, but the decline has been much greater in the East (24%) than in the West (17%). Although a decline might indicate a surplus of grazed roughages in the Nation's cattle production system, the decline in the East may be more related to shifts in cropland use from pasture to crop production (Gustafson 1983). The decline in the West, which also represents a shift from cropland pasture to crop production, may be truly representative of a surplus in forage, as much of the land grazed is forest and rangelands and not suitable for cropland.



NOTE.--East: NO and SO regions except Oklahoma and Texas;
West: all other regions and Oklahoma and Texas.
Source: USDA (1955-1986)

Figure 35.—Number of cattle in the eastern and in the western United States, 1955-1985.

FORAGE CONSUMPTION

National and Regional Forage Consumption by Livestock

Beef cattle and sheep represent the largest inventories of livestock that use grazed roughages in the United States. Dairy cattle make up a small part of the national inventory, and, since 1985, have declined further in response to the legislated dairy herd reduction program. Harvested forages, such as hay, and concentrate provide most of their diet. Gee and Madsen (1988) estimated that the annual consumption of grazed roughages by goats is about 3.6 million AUMs, a small amount nationally when compared with the consumption of 431 million AUMs by beef cattle and sheep (table 10). The demand for grazed forages by the 2 million farm horses is also small in comparison to beef cattle. The feed demand by horses, including recreational horses, could potentially be greater than the demand by sheep. The feed sources for recreational horses, however, are primarily purchased hay. Some hog production systems use pasture, but USDA Economic Research Service (1985) reported that less than 1% of hog feed costs are for pasture. Smith et al. (1980) estimated that hogs and horses consumed less than 3% of the total nutrients supplied by forages nationwide. Because the combined total demand for grazed forage by dairy cattle, goats, and horses is small compared with beef cattle and sheep, the consumption of grazed forages is analyzed only for beef cattle and sheep in this assessment.

The main sources of forage consumed by beef cattle and sheep are deeded nonirrigated rangeland and pasture, publicly owned grazing land (i.e., federal, state, local governments), deeded irrigated pasture, and crop residues. Although the importance of enterprise-owned land is evident in that this source provides over 70% of forage consumed by beef cattle and sheep (table 10), other sources may represent the only available forage during certain seasons of the year. The regional combinations of deeded land with other forage sources (table 18) is a function of the availability of other sources, the local environment, and the type of livestock operation. The large relative contribution of public grazing in the SW and the NR regions is a reflection of the extensive amount of public land in those regions (table 5). Because of the availability of public forage, a ranch may raise hay on private land to support the livestock during the winter. The regional significance of crop production as a land use is seen in the NO region (fig. 8) where crop residues are the only source, other than deeded land, associated with beef cattle operations (table 18). The availability of irrigation in the CA and the PN regions is evidenced by the importance of irrigated pasture here in contrast to other regions. Although irrigation is available in the SW region, specialty crops bring a higher return than irrigated pasture.

Table 18.—Consumption of grazed forages by beef cattle and sheep on an animal unit month (AUM) basis, 1985.

Region	Deeded non irrigated		Public grazing		Irrigated grazing		Crop residue		Total
	Thousand AUMs	Percent	Thousand AUMs	Percent	Thousand AUMs	Percent	Thousand AUMs	Percent	Thousand AUMs
					Beef Cattle				
PN	9,929	74	611	5	2,162	16	671	5	13,373
CA	12,118	79	1,048	7	1,702	11	498	3	15,367
SW	8,310	64	4,448	34	88	1	109	1	12,956
NR	95,746	81	11,452	10	3,804	3	7,777	6	118,780
NO	66,118	94	—	—	—	—	3,926	6	70,044
SO	167,137	92	6,603	4	801	T[1]	7,030	4	181,571
Total	359,359	87	24,163	6	8,557	2	20,011	5	412,090
					Sheep				
PN	254	31	466	57	41	5	57	7	818
CA	1,055	52	183	9	203	10	589	29	2,029
SW	838	59	298	21	100	7	185	13	1,421
NR	2,369	31	4,356	57	382	5	535	7	7,642
NO	2,184	70	—	—	—	—	936	30	3,120
SO	4,042	100	—	—	—	—	—	—	4,042
Total	10,742	56	5,304	28	725	4	2,302	12	19,073
					Beef Cattle and Sheep				
PN	10,182	72	1,078	8	2,203	16	729	5	14,191
CA	13,174	76	1,230	7	1,905	11	1,087	6	17,369
SW	9,148	64	4,747	33	188	1	294	2	14,376
NR	98,116	76	15,809	13	4,186	3	8,312	7	126,422
NO	68,303	93	—	—	—	—	4,862	7	73,165
SO	171,179	92	6,603	4	801	T	7,030	4	185,612
Total	370,101	86	29,466	7	9,283	2	22,312	5	431,163

Note: Totals may not add up as a result of rounding.
[1]*T = Less than 1%*
Source: Gee and Madsen (1988).

Crop residue, irrigated pasture, and public grazing supply a greater share of the feed mix for sheep than for cattle (table 18). Nationally, public grazing land contributes 28% of the total feed mix for sheep, whereas this is only 6% of the total feed mix for beef cattle. In the PN, and the NR regions, public grazing contributes more than 50% of the total feed mix for sheep whereas deeded non-irrigated land contributes only 30%. Nationally, crop residue contributes 12% to the total feed mix for sheep, but only 5% for beef cattle.

Total forage consumption estimates based on ranch/farm surveys (table 18) are compared with estimated feed requirements based on national livestock inventories (table 19). Over 670 million AUMs are needed to meet the total feed requirement of beef cattle (excluding cattle in commercial feedlots) (table 19). Based on the ranch budgets, 61% of this total feed requirement, or 431 million AUMs, is met by grazed forages (table 18). For sheep (excluding lambs in feedlots), 90% of the annual feed requirements are met with grazed forages (table 19). These percentages of the total feed mix supplied by grazed forages appear reasonable, given the distribution of livestock operations in the United States (Gee and Madsen 1988). Few areas have large beef cattle inventories and 12 months of grazed forages available, implying that a certain percentage of the cattle diet will need to be met with harvested forages or concentrates. In many areas, grazing is limited to 6 or 7 months because of adverse climatic conditions (Gee and Madsen 1988). Sheep are more dependent on grazed forages than cattle. Little supplementary feed is used in the production of sheep in the 17 western states with the exception of several months in the Northern Great Plains (Gee and Madsen 1988). These grazed forage estimates (table 18) form the basis for an examination of the regional distribution of grazed forages by livestock type, and the future demand of forage by livestock type.

Use of Livestock Forage on Public Lands

Permitted AUMs represent the amount of forage available for livestock grazing on public lands and were given as an estimate of the supply of forage from public lands (Chapter 2). Livestock are authorized to graze an allotment under a grazing permit, grazing agreement, livestock use permit, or other authorizing document. Annually, only about 1% of the grazing allotments on National Forest System (NFS) and BLM-administered lands are vacant (without a grazing agreement with a

Table 19.—January 1 inventory (1,000 head) of and estimated feed requirements (1,000 units) for beef cattle and sheep in the United States, 1985.

Livestock	Inventory	Animal units[1]	Animal unit months
Beef cattle:			
Cows that have calved	35,393	44,949	
Replacement heifers	6,183	3,833	
Steers 500 pounds and over[2]	6,560	4,067	
Bulls	2,411	3,014	
Total cattle		55,863	670,356
Sheep:			
Stock sheep 1 year and older			
Ewes	7,233	1,447	
Rams and wethers	314	63	
Stock sheep, lambs			
Ewes	1,016	203	
Rams and wethers	284	57	
Total sheep		1,771	21,252
Total cattle and sheep			691,608

[1]*Conversions to animal units are cows, 1.27; yearlings, 0.62; and bulls, 1.25. All sheep have the same animal unit value and five head equals one animal unit.*

[2]*Assumes 30% of steers in January inventory used grazed forages. The remainder went to feedlots for finishing.*

Source: Gee and Madsen (1988).

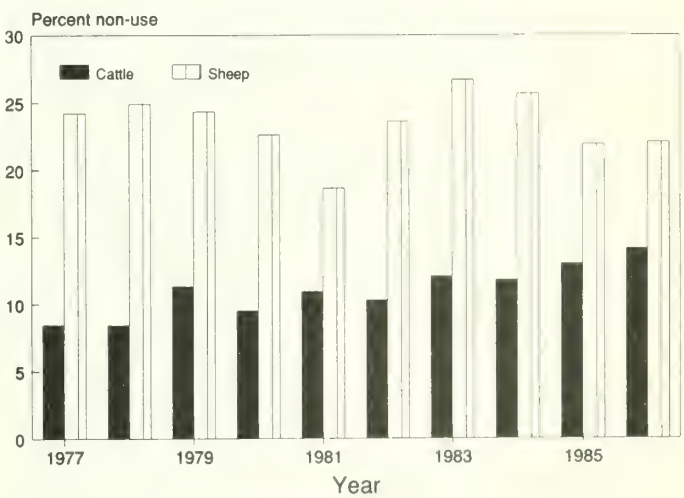
permittee) (USDA Forest Service and USDI Bureau of Land Management 1986). Most of these vacant allotments are high-elevation sheep allotments for which demand has declined because of remoteness, cost of operation, labor shortages, and the decline in the sheep industry. A permittee may elect to take non-use on an allotment. Non-use is an authorization to refrain from grazing livestock without the loss of preference for further consideration (USDA Forest Service and USDA Bureau of Land Management 1986). One indication of the demand for forage is the trend of those AUMs in non-use on NFS lands.[12]

Cattle non-use on NFS lands increased from less than 10% in 1977 to 14% in 1986 (fig. 36). Although permitted use on NFS lands has remained fairly constant from 1980 to 1986 (figs. 28-33), this increasing non-use reflects the general economic decline in the agricultural sector. This 1977-86 period coincided with the continual decline in the national cattle herd (fig. 34).

Sheep non-use fluctuated from a high of 26% to a low of 19%; no definite trend occurred in 1977-86. Although the sheep non-use percentage is higher than the cattle non-use, in terms of AUMs, this percentage represents a much smaller number of AUMs than cattle non-use. In 1980, total AUMs for sheep and goats (authorized to graze) were 1.1 million in contrast to the 8.5 million AUMs for cattle.

Regional trends of total non-use AUMs (cattle, horses, sheep, and goats) show a slight increase since 1977, reflecting the dominance of cattle AUMs. Trends in non-use are similar across the western regions (NR, PN, CA, SW), increasing from 10% in 1977 to about 15% in 1986 (fig. 37). Non-use in the eastern regions (NO and SO) was higher than in the western regions (fig. 37), perhaps reflecting the increased emphasis of crop production in the eastern regions.

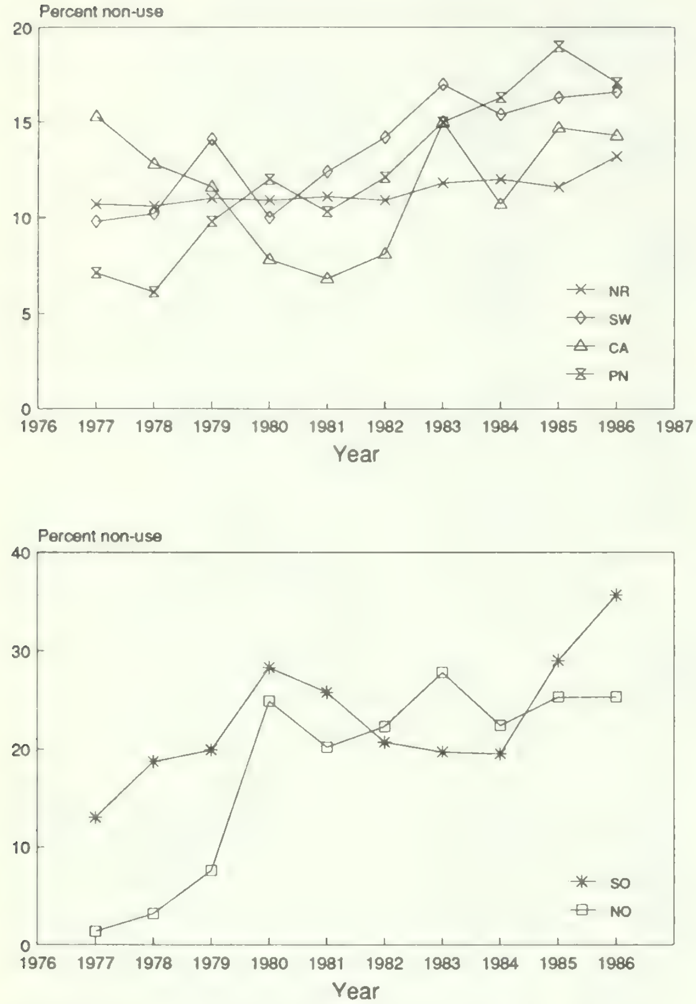
[12]*For this study, non-use percent is calculated as [1 – Actually grazed Paid Permits / Authorized to Graze] times 100 from data in the Annual Grazing Reprts of the Forest Service. No data was available for the BLM.*



NOTE.--Non-use = [1-(actually grazed paid/authorized use)].

Source: USDA, Forest Service (1978-1987)a

Figure 36.—Non-use of cattle and sheep permitted use on National Forest System lands.

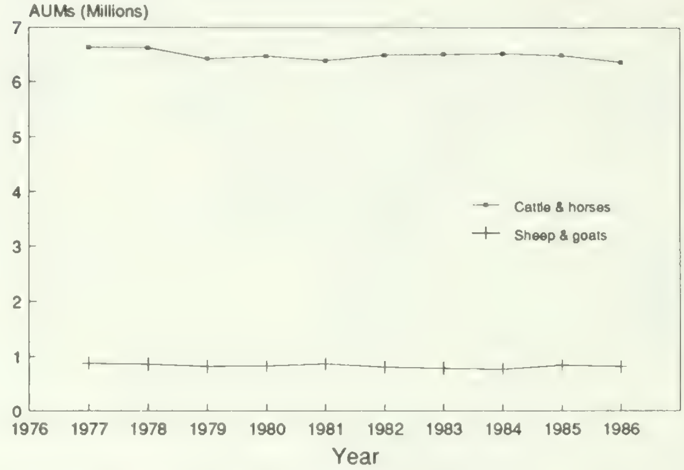


NOTE.--Non-use = [1-(actually grazed paid/authorized use)].

Source: USDA, Forest Service (1978-1987a)

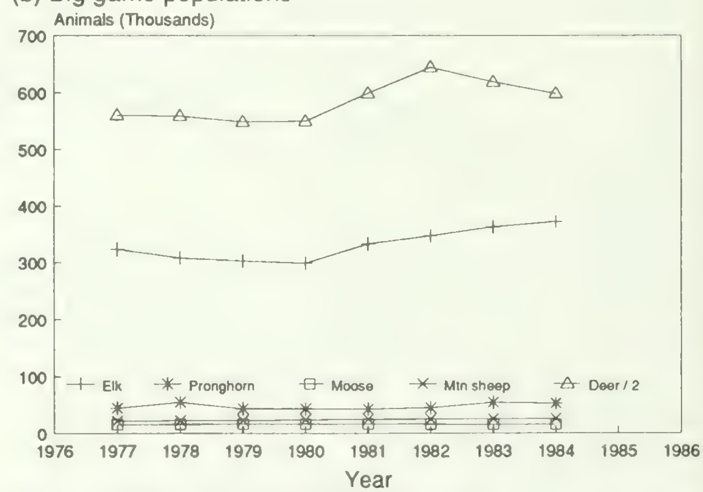
Figure 37.—Non-use as a percentage of authorized grazing on NFS lands by assessment regions.

(a) Paid permitted livestock use



Source: USDA, Forest Service (1978-1987a)

(b) Big game populations



NOTE.--Wildlife data only available to 1984.
Mountain sheep includes bighorn sheep and mountain goats.

Source: USDA, Forest Service (1978-1987b)

Figure 38.—Large herbivores using National Forest System lands in the Rocky Mountain region.

Wild Herbivore Populations and Domestic Grazing Use on National Forest System Lands

Wild and domestic herbivores graze forest and rangelands. Wildlife populations are not managed in the same manner as cattle and sheep. Livestock are managed for restricted movement, whereas wild herbivores migrate across the landscape in response to habitat, food, and water needs. Population estimates for NFS lands reflect wildlife use of those lands (Flather and Hoekstra in press, USDA Forest Service 1978-1987b), however the migratory habits of big game animals result in the use of different ownerships (surrounding private and other public lands) at different times of the year. Thus, trends in wildlife numbers reflect management from a mosaic of land ownerships. Livestock use on NFS lands is closely regulated and data on actual use by livestock (livestock actually grazed paid permitted AUMs) is reported yearly (USDA Forest Service 1978-1987a). Information was available to compare wild and domestic herbivore trends on NFS lands only.

Nationally, big game populations on NFS lands have remained stable or have increased, whereas livestock permitted AUMs have remained stable or declined since 1977 (fig. 28). Before 1977, mule and black-tailed deer populations declined across all ownerships. Domestic sheep AUMs on NFS lands have continued a steady decline (fig. 28). Big game abundance has increased most notably for moose, elk, and bighorn sheep.

In the Rocky Mountain region (NR and SW regions), livestock actual use has declined 4%, while numbers of deer and elk have increased 6% and 15%, respectively, over 1977-86 (fig. 38). Pronghorn numbers, small relative to deer and elk, have increased 17% since 1977.

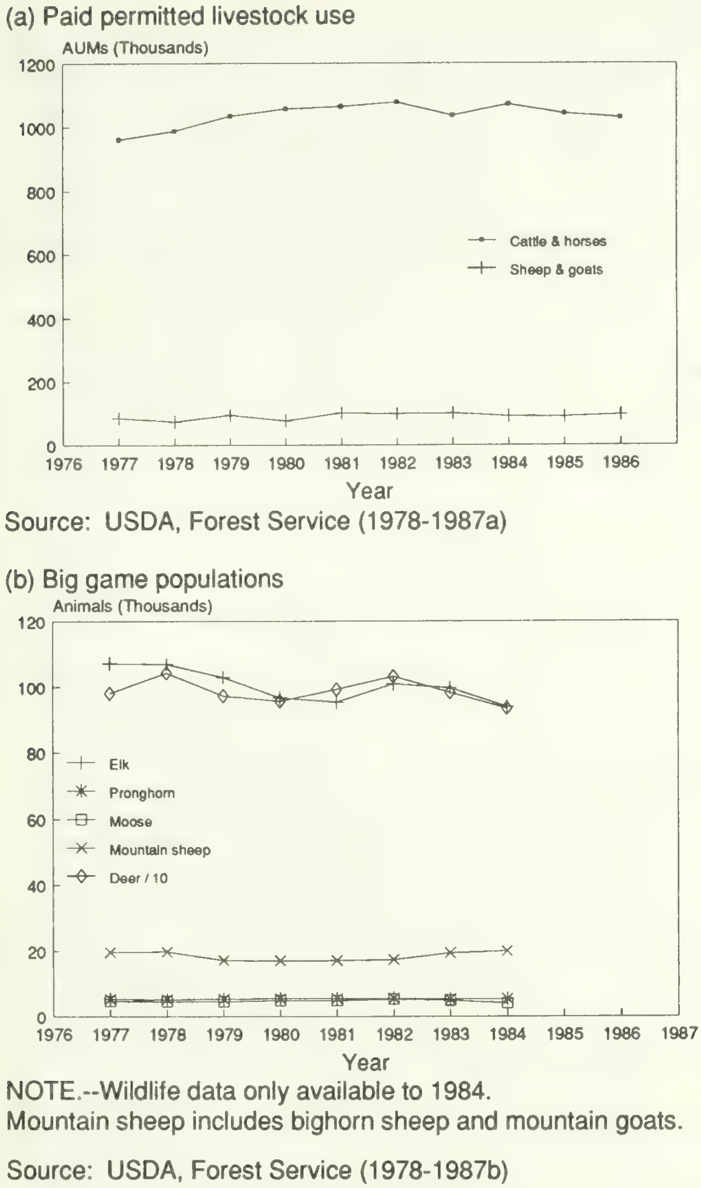


Figure 39.—Large herbivores using National Forest System lands in the Pacific Coast region.

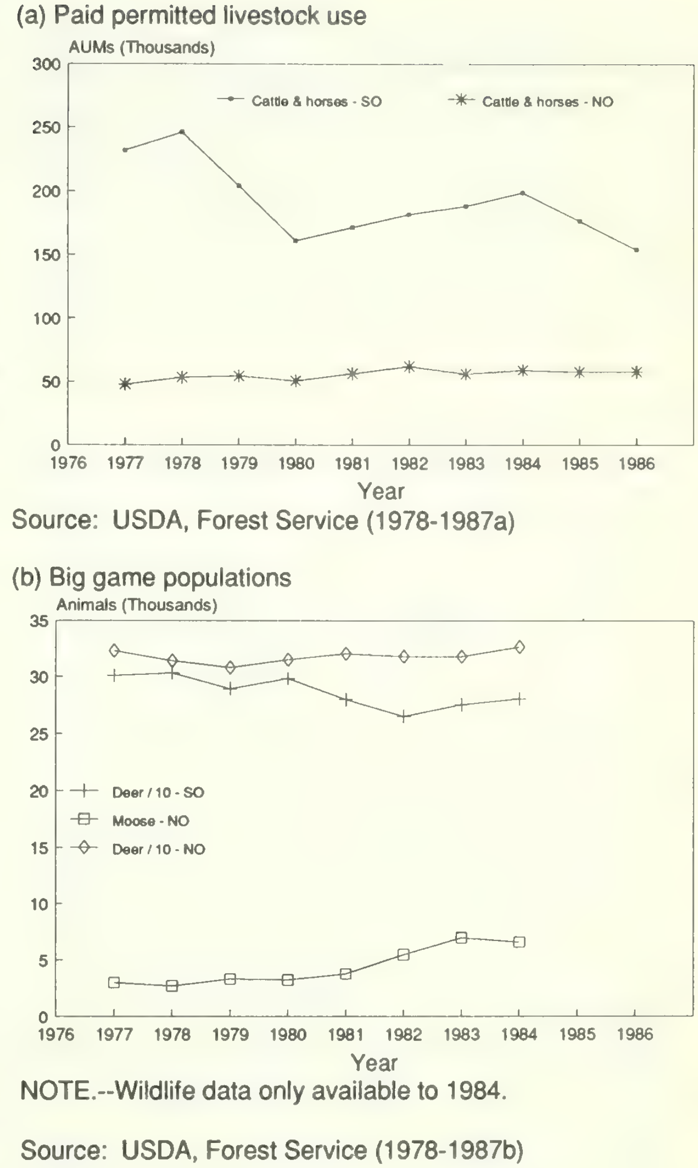


Figure 40.—Large herbivores using National Forest System lands in the eastern United States.

Moose numbers have remained relatively stable, while bighorn sheep numbers have increased 28% (fig. 38b).

In the Pacific Coast region (PN and CA regions), cattle and horse AUMs have increased 7% over the 1977 levels, while deer and elk numbers have declined 5% and 12%, respectively (fig. 39). The slight rise in wild mountain sheep (bighorn sheep and mountain goats) is a reflection of increases in mountain goat populations.

Large herbivore use on NFS lands in eastern United States (fig. 40) shows that in the NO region, cattle and horse AUMs have increased 21% since 1977. Domestic sheep use has declined 86%; AUMs dropped from 2 million in 1977 to 249,000 in 1986 in the NO region. Deer numbers on NFS lands have remained fairly constant, although declines in the 1970's possibly were related to declining forest land area in early successional stages (Flather and Hoekstra in press). Moose numbers have doubled in the NO region since 1977 (fig. 40b). In the SO region, livestock AUMs and deer numbers both declined in 1977-86, however the declines were greater for livestock (fig. 40). Over a longer period of time, white-tailed deer numbers appear to be stable, fluctuating between 250,000 to 300,000 animals (Flather and Hoekstra in press).

DEMAND FOR FORAGE BY LIVESTOCK

Beef Industry Structure

The availability of grazed forages is critical in two segments of the beef cattle industry: breeding herds and stocker cattle production. Little grazed forage is used in

this last segment of the beef industry, fed beef production, but this final step influences the retail product, and thus, can influence the demand for grazed forages. The objective of a beef cow-calf operation is to maintain and breed cows for the primary purpose of producing stocker calves and yearlings. Most stocker cattle enterprises seek to produce animals of weight and condition that will go easily into a finishing program upon entering commercial feedlots (Gee and Madsen 1988). Although some stocker cattle are slaughtered, most stocker cattle are placed in feedlots and fed grain and concentrates before slaughter.

Breeding Herds

Based on January 1 inventory numbers, the breeding herds are primarily in the SO (46% of the total), the NR (28%), and the NO (19%) regions (table 20). This regional distribution has changed little from 1978 to 1986. The largest increase in cow numbers was in the NR region with over 1 million additional cows and the largest decrease was in the NO region with about 500,000 fewer cows (Boykin et al. 1980, U.S. Department of Agriculture [various years]).

Nationally, less than 50% of all beef cows are in herds of more than 100 cows. Within the northeastern United States, small herds of less than 20 cows make up more than 50% of the total cow inventory, whereas in the western regions, less than 6% of the cow inventory is in small herds (Gilliam 1984). Operations are much larger in the western regions where 30% of the beef cows are in operations of 500 or more brood cows.

The number of producers with fewer than 20 brood cows represents a greater proportion of the total number of enterprises than these herds represent in the total inventory. About 60% of the nation's cow-calf enterprises have less than 20 brood cows. The remaining 40% manage more than 80% of the total cow herd (Gilliam 1984).

The types and costs of feed in the cow-calf operation reflect the location of the operation, the mix of native and seeded vegetation available within the operation, and the accessibility to other forage sources. Brood cows must be fed year-round and feed is needed to maintain the calves until weaning or shortly thereafter when they are sold to stocker operations. Cow-calf operations normally rely on grazed forage as the primary feed source because of the relative low cost. Yet, grazing in the cow-calf operation comprises more than half of the total direct production cost (Gilliam 1984). Snow cover, drought, or poor nutritional quality during some seasons necessitate additional feed from harvested forages, such as hay or silage (Gee and Madsen 1988).

The amount of land used only for grazing (dry range and irrigated pasture) within cow-calf operations increases from eastern to western United States and as the size of the cow-calf operation increases (table 21). The importance of rangeland also increases from east to west, wherein 95% of the grazed forage is supplied from range and native pasture. In the western regions, 80% of the enterprises sell only beef cattle and less than 50% of the western operations sell any other crop, excluding hay (Gilliam 1984). Western cow-calf operations are primarily beef operations using predominantly range grazing as feed.

Small cow-calf operations generally use larger percentages of secondary sources of grazing, such as corn, grain sorghum, soybeans, and other cropland after the crops have been harvested (table 21). The relatively large acreage associated with crop residues in the North Central and Southern regions (table 21) reflects the fact that most cow-calf operations in these regions are supplemental enterprises located on farms primarily producing crops and other livestock products, such as hogs (Gilliam 1984). In some regions, crop residue grazing may represent the only forage available during that season (Gee and Madsen 1988). Thus, the significance of the feed sources is not apparent from the magnitude of feed supplied, but rather the availability of substitutes for that feed during that season.

The estimates of forage sources in table 21 do not include any public land or private grazing leased or rented. The implication of this additional feed source can be surmised in the forage diversity of western ranches where public land is more common. Ranches

Table 20.—Inventory of beef cows (1,000 head) by Assessment region in 1978 and 1986.

Region	1978 Beef cow numbers	1978 Percent of total	1986 Beef cow numbers	1986 Percent of total
California	966	2.5	1,305	3.2
Pacific North	986	2.5	1,240	3.0
Northern Rocky	10,153	26.1	11,479	28.1
Southwest	917	2.4	951	2.3
Northern	7,600	19.6	7,126	17.4
Southern	18,104	46.9	18,807	46.0
Alaska	NA	NA	4	T[1]
11 Western States	6,886	17.6	7,542	18.4
United States	38,726	100.0	40,912	100.0

[1] *Trace.*

Source: 1978 data: USDA Economic Research Service (1979). 1986 data: U.S. Department of Agriculture (1987), Agricultural Statistics.

Table 21.—Acres per cow of various forage sources grazed within beef cow-calf farms and ranches, 1980.[1]

Region and forage source	Cow herd size (head)			
	20-99	100-499	500 or more	All sizes
South[2]:				
Annual pasture	0.14	0.18	0.15	0.15
Seeded perennial pasture	2.05	1.68	2.15	1.96
Native pasture	0.38	1.21	2.36	0.88
Hay aftermath	0.78	0.41	0.20	0.60
Crop residue	0.38	0.09	0.03	0.25
Total	3.73	3.57	4.89	3.84
North Central:				
Annual pasture	0.04	0	0	0.03
Seeded perennial pasture	1.53	2.20	3.90	1.75
Native pasture	1.05	0.33	1.56	0.90
Hay aftermath	0.26	0.61	0.18	0.34
Crop residue	0.20	0.58	0.23	0.28
Total	3.08	3.72	5.87	3.30
Great Plains:				
Irrigated pasture	0.03	0.01	T[3]	0.02
Small grain pasture	0.01	0.02	0.40	0.07
Dry range	8.80	12.74	27.22	12.96
Hay aftermath	0.33	0.29	0.08	0.28
Crop residue	0.21	0.12	0.02	0.15
Total	9.38	13.18	27.72	13.48
West:				
Irrigated pasture	0.83	0.34	0.39	0.47
Small grain pasture	T	0	0	T
Dry range	15.08	18.59	23.93	19.34
Hay aftermath	0.80	0.54	0.53	0.60
Crop residue	0.04	0.05	T	0.03
Total	16.75	19.52	24.85	20.44

[1]*Excludes BLM and FS grazing, and grazing leased or rented from all other sources.*

[2]*These regions differ slightly from the Assessment regions: South here includes all states in Southern region except OK and TX; North Central here includes all states in Northern region except ME, NH, VT, MD, PN, NY, RI, MA, and northern parts of MI, MN, WI; Great Plains here includes ND, KS, OK, TX, the eastern parts of SD and NE, and the Front Range parts of CO, and NM; the Western region here includes all of the Western states except those parts in the Great Plains region.*

[3]*T = less than 0.005 acre.*

Source: Gilliam (1984)

in the Great Plains are more dependent on dry (native) range than western ranches. Ranches in the West are more likely to have up to 5% of their feed source from irrigated pasture (table 21). The presence of hay aftermath as a grazing source indicates that these lands can be set aside for the production of hay. Western ranches had at least 2% of their lands in hay production and, in some size classes, as much as 5%. Great Plains ranchers had lesser amounts of hay production within each size class. The availability of federal or private-leased forage increases the ranches' flexibility in determining the total feed mix for the enterprise. Any change in this availability would require substantial changes in feed production.

Although additional forage production can be obtained by improvement, such as fertilization, a 1976 survey of cow-calf producers indicated that western range is rarely fertilized. During a 1981 survey, only 8% and 19% of native pasture in the SO and NO regions, respectively, were fertilized (Gilliam 1984). Fertilization rates on seeded pasture were much higher. Forage improvement practices are implemented only when profitable. Recent economic factors have not encouraged the implementation of forage improvement practices, especially on rangeland (Pope and Wagstaff 1987a, Wilson et al. 1987). If the economic situation warranted, additional forage could be produced on the available land in every region by applying various improvement practices (tables 11 and 12).

Stocker Cattle

In 1986, stocker cattle were located primarily in the NO (36% of the total), SO (28%), and NR (27%) regions (table 22). Since 1978, stocker cattle inventories have declined less than 7% in the 11 western states. In contrast, a decline of over 3.8 million head, or 24%, was seen in the SO region. Stocker cattle numbers inventoried during the summer would show a shift from these January 1 numbers as cattle are usually bought for stocker operations in the winter and early spring and

Table 22.—Inventory of stocker cattle (1,000 head) in 1978 and 1986 by Assessment region.

Region	1978 Stocker[1] numbers	1978 Percent of total	1986 Stocker[2] numbers	1986 Percent of total
California	1,207	3.0	1,695	4.4
Pacific Northwest	924	2.2	1,016	2.6
Northern Rocky	10,602	26.0	10,214	26.6
Southwest	822	2.1	647	1.7
Northern	12,771	31.3	13,887	36.2
Southern	14,448	35.4	10,933	28.5
Alaska	NA	NA	T[3]	T[3]
11 Western States	6,483	16.0	6,078	15.8
United States	40,774	100.0	38,395	100.0

[1]*Includes steers and "other" nonreplacement heifers weighing 500 pounds and over, plus steers, heifers, and bulls weighing under 500 pounds, minus cattle and calves on feed.*
[2]*Includes "other" nonreplacement heifers, steers, and calves, minus cattle on feed. Does not include 2,000 cattle on feed reported in "Other States" in source.*
[3]*Trace.*
Source: 1978 data: USDA Economic Research Service (1979). 1986 data: U.S. Department of Agriculture (1987), Agricultural Statistics.

moved to range and pasture for the growing season. However, the magnitude of these shifts would be small, and these January numbers show relative distribution of operations (table 22).

Stocker operations depend primarily on grazed forage as a feed source, but differ in the levels of management, capital inputs, and alternative feed sources. These production systems depend on starting weights of the calves, weights at marketing, length of feeding period, and kind of feed. One type of system purchases animals in late winter, pastures them for the summer, and sells them in the fall. The advantage of this system is the low cost of gain and the short feeding period which reduces price risk. This system involves less chance for large negative price margins than with other systems because the period the cattle are held by the operator is short, essentially just the growing season (Gee and Madsen 1988). Other systems purchase calves in the late fall and feed a ration of alfalfa hay or corn silage and small amounts of grain or other concentrates until grazed forage is available. These animals are held until spring or the following fall depending on cattle price fluctuations.

Two factors have encouraged increasing numbers of stocker operations to market cattle at heavier weights (Gee and Madsen 1988). Commercial feedlots have attempted to reduce feeding costs, increase the rate of turnover, and reduce price risks by beginning with heavier stocker cattle. Cow-calf producers have increasingly held calves after weaning to capture potential profits from additional growth and more benefits from herd improvement programs (Gee and Madsen 1988). In eight major cattle feeding states, the proportion of calves weighing less than 500 pounds in commercial feedlots in 1984 was only 52% of the proportion of lighter calves in the 1965 inventory (Gee and Madsen 1988). Heavier stocker cattle imply increased use of grazed forages and further trends in this direction would imply an increased demand for grazed forages nation-wide.

Sheep Industry Structure

Like the cattle industry, the sheep industry can be divided into breeding herds and fed animal (lamb) production. Lamb feeding operations vary from 1,000 to 50,000 animals (Council for Agricultural Science and Technology 1982). In 1980, nearly 43% of the lamb crop was sold to commercial feedlots or packing houses for fattening (Gee and Madsen 1983). This percentage varies across regions in relation to the availability of lush forage. In the Pacific Coast, weaned lambs can be sold for immediate slaughter. However, in drier parts in the Great Plains area and in the Southwest region, few lambs are considered fat enough for slaughter and these lambs are often fed in drylot facilities or grazed on crop residues such as beet tops or alfalfa stubble. Thus, unlike stocker cattle operations, fed lamb operations are often part of the breeding operation, and more often depend upon crop residue than range grazing to produce the animal to be sold to the feedlot. The breeding operations demand the greatest amount of grazed roughages in sheep production.

Of the 115,000 sheep enterprises in 1985, nearly 92,000 were located in the 17 western states and the 7 North Central states (American Sheep Producers Council Inc. 1987).[13] Characteristics of sheep operations vary with size and location. Nationally, 43% of producing ewes were in herds of 1,000 or more in 1978. Large herds (1,000 to 5,000 animals) were more common in the 17 western states (Gee and Madsen 1983). Farm flock

[13]*North Central states of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio.*

operations of less than 50 producing ewes are common in the midwestern and northeastern parts of the United States. A slight shift between 1969 and 1978 away from the medium-sized herds (100-199) to either herds of over 1,000 or less than 100 head may reflect the renewed interest in small farm flocks (Gee and Madsen 1983).

Important feed sources for sheep are public grazing and deeded nonirrigated pasture (table 18). In 1980, 1.8 million sheep grazed BLM-administered land and 1.3 million grazed on NFS lands, which represent 29% and 21%, respectively, of sheep in the western states. Since many operators use only one of these feed sources, these percentages may not represent the same sheep and 30% to 40% of all western sheep may rely on federal land (Gee and Madsen 1988). Operators may graze only part of their herd on public land, thus if all sheep within an enterprise are included, potentially more than 50% of sheep in the 17 western states are owned by enterprises affected by federal grazing land policies (Gee and Madsen 1988).

The large decrease in sheep inventories since the 1960s has significantly reduced the demand for grazed forage on traditional sheep ranges in the western United States. This grazing land has also been diverted to other uses, reducing the amount of federal land available for sheep grazing (Gee and Madsen 1983). Stable inventories since 1980 suggest that demand for forage will continue at the current levels.

Seasonal Dependency on Forage

The total feed mix for a livestock operation is a combination of many feed sources available at different times of the year. Sources, such as hay, are used to supplement unavailable or short supplies of feed. Seasonal availability of forage is a function of climate, management, land ownership patterns, and land use patterns. Management activities can mitigate the seasonal supply of forage by diversifying the type of plant species grown, such as extending warm-season pastures with the seeding of cool-season species in the South, or seeding warm-season species into the predominantly cool-season pastures in the North. In the western United States, livestock grazed public lands before these lands were managed as federal ownerships. These patterns of intermixing private with public grazing established a precedent for the historical dependency of grazing upon federal lands for at least part of the yearly forage needs (Bedell 1984).

When dependency is defined as AUMs of feed provided by public lands divided by total annual AUMs required by the entire livestock herd, the dependency level for cattle operations ranges from 11% to 60% across the 17 western states (USDA Forest Service and USDI Bureau of Land Management 1986). For sheep operations, the dependency levels range from 24% to 49%. In states such as New Mexico, livestock may graze federal land for the entire year, whereas in other states such as Montana, a seasonal use is more common.

The absolute magnitudes of these dependencies may not adequately reflect the potential changes in livestock operations if these seasonal sources of forage are changed. The actual impact will be a function of how the seasonally available sources interact with other sources of feed. For example, April, May, and June are critical feed months in eastern Oregon, and ranches with access to BLM grazing during this time can carry a larger herd in other months of the year (Bedell 1984).

Although ownership patterns contribute to seasonal dependencies, land use patterns also foster seasonal availabilities in forage sources. In southern Kansas, Oklahoma, and the Texas panhandle, wheat is planted in the fall, and with favorable moisture, the crop provides ideal winter pasture for several hundred thousand calves (Gee and Madsen 1988). Fields can be grazed under proper management from October or November to March, without harm to the wheat crop. The use of this stocker system varies with the annual changes in moisture, and, under dry conditions, very few cattle will be grazed on the wheat pastures (Herbel and Baltensperger 1985).

TECHNOLOGICAL ENHANCEMENTS IN LIVESTOCK PRODUCTION

Technological Developments and their Influence on Livestock Production

The development and implementation of technology and its influence on animal production changed the use of forest and range vegetation (table 23). The introduction of cattle, horses, and sheep to North America changed the mix of grazers in forest and rangeland ecosystems. The development of refrigeration (1801), livestock shipment by rail (1852), and refrigerated railroad cars (1868) extended the distance from markets that livestock could be produced. As a result, vast areas of grazingland were opened in the interior of the United States. The development of the windmill (1854) improved the distribution of livestock across the landscape. Mechanical developments such as the hay baler and the grain elevator (1842) allowed forage harvested in years of good precipitation to be stored and used in drought (Smith 1979, Taylor 1984). The development of irrigation (1847) in the semi-arid west, and the introduction of improved forage species (1884 and 1888) diversified and nutritionally improved the feed mix and began to shift the use of land from grazing to cropping.

Technology has increased the type and quantity of outputs from the grazing animal. The introduction of exotic breeds (1817) and the development of growth stimulants (1949) have helped to increase meat or milk production per animal. Alternative livestock products such as angora (1849) diversified the grazing industry. The widespread implementation of artificial insemination (1939) and the development of drugs for estrous synchronization (1979) increased an operator's ability to genetically improve livestock production.

Table 23.—History of developments affecting rangeland management in the United States.

Year	Development
1636	First meat packing plant
1783	Improved cattle introduced to United States
1801	Refrigerator invented
1817	First Hereford and Jersey imported to United States
1834	Mechanical refrigeration developed
1836	First recorded auction sale of livestock in Ohio
1837	John Deere plows with steel share and smooth wrought iron moldboard
1842	First grain elevator in Buffalo, New York
	First rail shipment of milk
1843	Commercial fertilizer industry began
1847	Irrigation agriculture initiated in Utah
1849	Angora goats introduced to United States
1852	First livestock shipment by rail
1854	Windmill invented, Connecticut
1863	Dryland farming in Utah
1865	Chicago's Union Stockyards opened
1866	Goodnight and Loving trail cattle from Texas to Colorado and New Mexico
1867	First patent for barbed wire fencing, New York
1868	Refrigerated railroad car patented
1869	Transcontinental railroad completed
	Fresh meat successfully shipped from Chicago to Boston in refrigerated railroad cars; cooled by ice and salt
1874	Glidden barbed wire patent granted
1875	First continuous shipments of beef to England
1884	Smooth brome grass introduced
1886-87	Disaster in Great Plains cattle industry; winter storm, drought, overgrazing; this extends plowed agriculture into semi-arid and arid sections of United States
1888	Crested wheatgrass introduced from Russia
1888	Meat first shipped in railroad cars with mechanical refrigeration
1895	Commercial feed industry began in Chicago
1915	Refrigerated warehouse construction in meat packing plants
1927	Federal grading of beef initiated
1930	Range Livestock Research Station established at Miles City, Montana
1939	Artificial insemination widely used
1941	First performance bull testing station (Texas)
1942	Growth regulation property of 2,4-D discovered
1949	Usefullness of antibiotics in animal nutrition demonstrated
1950	Commercial feeding of stilbestrol to beef cattle began
1952	First successful breeding using frozen semen
1960	Cubing and wafering machines revolutionized hay handling
1960	Boxed beef processing began to influence industry
1978	First calf from a frozen embryo in the United States
1979	Diethylstilbestrol banned from use in cattle feeding
1979	First prostaglandin (Lutalyse) approved for use in estrous synchronization
1981	First test tube calf born in the United States
1982	First identical twin calves born in the United States as a result of microsurgery

Source: Smith (1979), Taylor (1984).

Increased feeding efficiency in animals has led to the doubling of market weights (Fontenot 1984). Live weight marketed per breeding female in beef cattle has gone from 220 pounds in 1925 to 317 in 1950 to 482 in 1975. Live weight marketed per breeding female of sheep has risen from 59 pounds in 1925 to 90 in 1950 to 130 in 1975. Milk marketed per breeding female in dairy cattle has risen from 4,392 pounds in 1925 to 10,513 in 1975. One half the cow numbers are producing the same quantity of milk produced 30 years ago using one-third less feed (National Research Council, Board on Agriculture, Committee on a National Strategy for Biotechnology in Agriculture 1987).

Although many technologies have been developed to improve livestock production and the efficiency with which livestock harvest forage, the implementation of these technologies is lacking on rangelands (Lewis and Engle 1982). On the Great Plains, conventional barbed and woven wire are the most commonly used fencing technologies and solar-powered electric energizers are one of the least commonly implemented fencing technologies (table 24). Technologies to benefit both livestock and wildlife have had limited application. Antelope pass fencing is fully developed but has had little or no application (table 24).

Fed Beef Production

Fed beef are cattle that have been fed a fattening ration for the slaughter market. Stocker calves weighing from 500 to 750 pounds are purchased, fed a fattening ration for 4 months to 1 year, and sold at weights between 900 to 1,200 pounds (Nelson 1984). Little forage is used in this segment of the beef production, however this segment produces the final product and, thus, influences the supply and demand of meat.

At one time, all grain-fed beef cattle were produced on farms, and the major center of fed beef production was the Corn Belt states (Gee and Madsen 1988, Van Arsdall and Nelson 1983). In 1950, less than 40% of the cattle on feed were in the 17 western states. The development of irrigation, hybrid sorghum grains, and increased grain production in the Great Plains and West initiated shifts in the regional distribution of cattle feeding operations. Preceding and coincident with these agricultural developments were a number of discoveries related to beef nutrition and pest and disease control. These discoveries allowed for increased concentrations of cattle (Reimund et al. 1981). Commercial feedlots with a capacity of 16,000 head or more accounted for only 16% of the marketings in 1967, but by 1984, feedlots of this size had cornered 51% of all fed beef marketings (Gee and Madsen 1988). Whereas farmer-feedlots were vertically integrated with feed grain production and cattle feeding occuring during seasons when labor was not needed for crop production, these large commercial feedlots could separate grain production from livestock feeding, operate year-round, and reduce the seasonality of fed-beef production (Reimund et al. 1981). These technological advances coupled with the strong consumer demand for beef fueled the rapid expansion of cattle feeding during the 1960s and 1970s (Van Arsdall and Nelson 1983). In 1960, the proportion of the calf crop slaughtered as nonfed was 21%. By the early 1970s, this proportion dropped to 5% (Reimund et al. 1981). In

Table 24.—Status of development and application of facilities and equipment used to manage animals for managing and improving range ecosystems of the Great Plains.

Facility or equipment item[1]	Status of development[2]	Extent of application[3]
A. Fencing		
1. Conventional barbed or woven wire	3	3
2. Big game fencing	3	2
3 Suspension fencing	3	1
4. Electric, conventional	3	3
5. Electric, high efficiency	3	1
6. Solar-powered electric energizer	3	1
7. Mechanized fence builder	3	1
8. Antelope pass fencing	3	1
B. Water developments		
1. Improvement of natural supply	3	3
2. Wells, wind or power pumped	3	3
3. Deep wells	3	1
4. Reservoirs and dugouts	3	3
5. Rain catchments	3	1
6. Storage facilities	3	1
7. Piping	3	1
8. Heaters, propane	3	2
9. Heaters, solar-powered	2	1
C. Handling and animal management		
1. Corrals, related facilities	3	3
2. Portable corrals	3	1
3. Identification		
Fire branding equipment	3	3
Freeze branding equipment	3	2
Ear tags and bands	3	2
Electronic	1	1
Telemetered	3	2
4. Weighing		
Conventional scale	3	2
Electronic, automatic recording	1	1
5. Windbreaks, shelter, shades	3	2

[1]*Equipment and facilities are grouped according to their principal use. It is recognized that many have a variety of applications.*
[2]*Status of development:*
1 = Undeveloped.
2 = Various stages of development, not available for general use.
3 = Fully developed and available for use; refinements may be made in existing equipment.
[3]*Extent of optimum application:*
1 = None or very limited.
2 = Significant, but incomplete.
3 = Complete or near complete.
Source: Lewis and Engle (1982).

1984, 76% of the cattle on feed were in the 17 western states (Gee and Madsen 1988).

Although fed beef production occurs in most states, the largest production is located in 13 states: Texas, Nebraska, Kansas, Colorado, South Dakota, Minnesota, Iowa, Illinois, Indiana, Ohio, Michigan, Arizona, and California. In the last 5 years, marketings declined in two of the leading cattle feeding states (Iowa and California). The trend toward more specialization, low returns from cattle feeding, and a greater emphasis on crop production in Iowa contributed to this reduction because feedlots are generally small and part of a diversified farming operation (Gee and Madsen 1988). In California, most feedlots are large commercial operations and their decline reflects declines in slaughter plant facilities, the high costs of production associated partly with transportation of both cattle and feed into the state, and a reduction in the fed beef price premium enjoyed in past years (Gee and Madsen 1988). Fed beef marketings have been expanding fairly consistently in Colorado, Kansas, Nebraska, Texas, and Washington. The construction of new slaughter plant facilities, a surplus of feed grains, and plenty of easily accessible stocker cattle facilitates this expansion (Gee and Madsen 1988). In future years, cattle feeding will be concentrated more in the Central Plains with declines in the extreme Southwest and Cornbelt (Drabenstott and Duncan 1982, Gee and Madsen 1988).

Although the total costs are lower for large commercial feedlots, these operations are more sensitive to price

variations on inputs because nearly 99% of their total costs are variable costs. Commercial feedlots generally buy all their feed, whereas farmer feedlots are diversified operations in which all or a great proportion of the feed is produced on the farm (Van Arsdall and Nelson 1983). Variable costs were only 84% of the farmer feedlot total costs in 1979 (Drabenstott and Duncan 1982). Thus, shifts in the price of grain through rising exports, or changing government agricultural policies, affect fed beef production.

Future Technologies for Livestock Production

The future productivity of livestock could be increased by the development and implementation of 150 current and potential technologies (U.S. Congress, Office of Technology Assessment 1986b). These technologies span the entire spectrum of animal production from modifying and controlling the animal's environment to pest and disease control to manipulating and changing the animal's physiology (table 25). Many technologies currently exist to control pest and disease and to improve livestock reproduction rates. Genetic research has focused on altering livestock to improve reproductive performance, weight gain, disease resistance, or livestock coat characteristics (U.S. Congress, Office of Technology Assessment 1988). Enhancing the rate and efficiency of muscle growth to produce a leaner animal may be possible in the near future through the administration of recombinant hormones. Technologies currently exist that can optimize tissue growth through the synchronization of nutrition with the animal's need for protein growth. Technologies are needed that allow more precise regulation of growth in animals and integrated growth management programs that will coordinate the application of these technologies in a holistic approach (National Research Council, Committee on Technological Options to Improve the Nutritional Attributes of Animal Products 1988).

The impact of these emerging technologies on animal production efficiency is expected to increase the pounds of meat per pound of feed from the actual 1982 value of 0.07 to 0.072 by 2000, and increase the number of calves per cow from the actual 1982 value of 0.88 to 1.0 in 2000 (U.S. Congress, Office of Technology Assessment 1986b). This indicates an annual increase of 0.2% in feed conversion efficiency and 0.7% in calving success.

The impact of these technologies on the forage demand from forest and rangelands is difficult to determine. Increases in feed efficiency will produce more meat per pound of feed, a distinct advantage in feedlots. Kalter and Tauer (1987) reported that the greatest near-term economic potential involves the use of bio-tech-created natural hormones in animal protein synthesis. Adoption of these technologies will result in improvements in feed efficiency, increased milk production, reductions in the total nutrient requirements for animals, and lower crop, land, and consumer prices. Land for grain and roughage production could decline 3.4 to 10 million acres (Kalter and Tauer 1987).

Table 25.—Emerging technologies for animal production and likely year of introduction under three future environments of technological development.

	Technology environments		
	More new technology[1]	Most likely[2]	Less new technology[3]
Genetic engineering:			
Production of pharmaceuticals	1982	1982	1982
Control of infectious diseases	1983	1983	1983
Improvements in animal production	1990	2000	>2000
Genetic abnormalities			
Detection	1990	1995	>2000
Treatment	1990	2000	>2000
Control of cancer and leukemia	1990	1990	>2000
Animal production:			
Cycle regulation	1985	1989	1995
Superovulation, embryo transfer, and embryo manipulations	1983	1983	1983
Improvement of fertility	1990	1995	1995
Genetic engineering techniques for farm animals	1995	2000	>2000
Regulation of growth and development:			
Muscle and adipose tissue accretion	1987	1992	>2000
Hormone, serum, and tissue factors important to growth	1995	2000	>2000
Immunological attraction of animals	1990	1995	>2000
Measuring body composition and animal identification	1990	1995	>2000

Table 25.—Continued

	Technology environments		
	More new technology[1]	Most likely[2]	Less new technology[3]
Animal nutrition:			
Animal production consumption and human health	1995	2000	>2000
Alimentary tract microbiology and digestive physiology	1989	2000	>2000
Voluntary feed intake and efficiency of animal production	1989	1995	>2000
Maternal nutrition and progency development	1984	1984	1984
Livestock pest control:			
Slow release insecticides	1984	1984	1984
Vaccines	1986	1986	1991
Integrated systems	1987	1989	1994
Modification of insect habitat	2000	2000	2000
Insect-resistant animals	2000	2000	2000
Utilizing immunity systems	1990	1990	1995
Disease control:			
Data management and systems analysis	1980	1980	1980
Diagnostic methodologies	1986	1986	1988
Selection for disease resistance	1994	1999	>2000
Genetic engineering			
Embryos	1995	1999	>2000
Micro-organism	1988	1989	1999
Immunobiology	1983	1983	1983
Environment and animal behavior:			
Energy conservation:			
Non-integrated system	1985	1990	2000
Integrated system	1995	2000	>2000
Optimizing total stress	1995	2000	>2000
Stress and immunity	1995	2000	>2000
Photoregulation of physiological phenomena	1990	1990	>2000
Utilization of crop residues and animal wastes:			
Energy from manure	1985	1985	1985
Energy from crop residues	1990	1990	>2000
Animal feed from crop residue	1990	1990	>2000
Animal feed from manure	1990	1995	>2000
Monitoring and control technologies:			
Sensors, controllers, displayers	1985	1985	1985
Communication and Information management:			
Networks, software, and database systems	1985	1985	1985
Manufacturing management systems	1987	1990	2000
Expert systems	1992	1995	2000
Telecommunications:			
Digital communication	1990	2000	>2000
Fiber optics	1990	2000	>2000
Videotex and teletext	1985	1985	1985
Value-added networks	1985	1985	1985
Integrated services digital network	1987	1990	2000
Remote sensing	1985	1985	1985

[1]*Assumes to year 2000: (1) a real growth rate in research and extension expenditures of 4%, and (2) all other factors more favorable than those of the most likely environment.*

[2]*Assumes to year 2000: (1) a real growth rate in research and extension expenditures of 2%, and (2) the continuation of all other forces that have shaped past development and adoption of technology.*

[3]*Assumes to year 2000: (1) no real growth rate in research and extension expenditures, and (2) all other factors less favorable than those of the most likely environment.*

Source: After U.S. Congress Office of Technology Assessment (1986b).

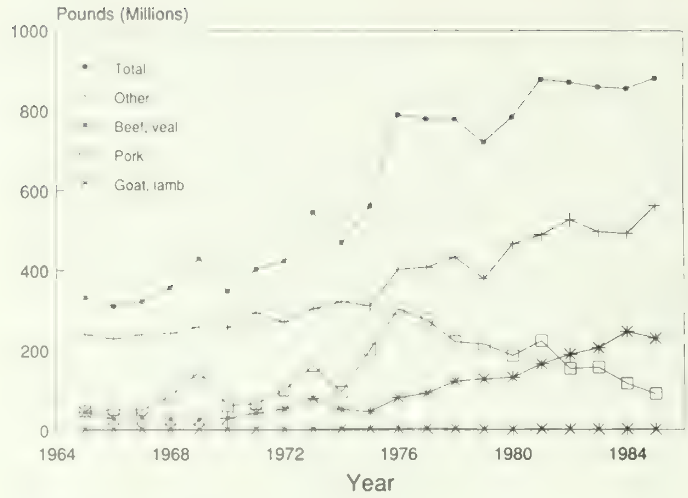
DEMAND FOR MEAT

World Production and International Trade

The world meat output that enters international trade is only 7% of total world meat production. Bovine meat, which includes beef, had the largest share of the international meat trade; poultry has been the fastest growing segment (Food and Agriculture Organization 1983). The United States share of the international meat trade (bovine, sheep, poultry, and pork) was only 4.6% in 1980. By type of product, U.S. meat exports have increased (fig. 41), but these exports were less than 1.5% of total U.S. meat supplies in 1985 (U.S. Department of Agriculture [various years]). Lamb and mutton exports were 1% of sheep supplies in 1985. Pork exports were 1.6% of total pork supplies, a drop from the peak of 3.1% in 1976 (fig. 41). Beef exports have increased since 1970, but these exports were only 1.5% of the total beef supplies in the United States in 1985 (table 26).

World-wide agricultural exports during the 1970s reflected a combination of favorable factors: increased meat imports by the Soviet Union as it profited from higher oil and raw material prices, rapid income growth in developing countries used to improve diets, rapid export growth in developing countries, increased ability to borrow against oil supplies, and currency exchange rates, particularly the exchange rate of the U.S. dollar (Sanderson 1984). Countries such as the United States increased their share of the world meat exports by improved beef production technologies. The economic recession of the 1970s and higher meat prices in the early 1980s led to increased self-sufficiency rates for meat production (Food and Agriculture Organization 1983). Beef and veal production increased from 1961 to 1984 in Eastern Europe, USSR, North America, and Africa and Asia (fig. 42).

Depressed prices in the world meat trade were the result of a slack demand, continued rapid technological improvements in animal production, and protectionist policies (Food and Agriculture Organization 1983). Protectionist policies for the livestock sector have



NOTE.--Other includes sausage, bologna, variety meats, canned meat, and meat products.

Source: USDA (1965-1986)

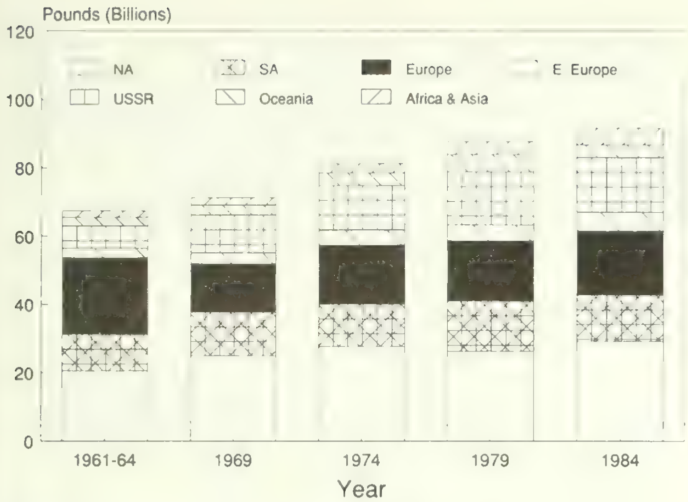
Figure 41.—United States meat exports by type of product.

Table 26.—Beef supply and foreign trade for United States, 1970-85.

	Supply (million pounds)			Percentage of total supply	
Year	Total	Imports	Exports and shipments	Imports	Exports and shipments
1970	23,830	1,792	101	7.5	0.4
1971	23,976	1,734	117	7.2	0.5
1972	24,739	1,960	114	7.9	0.5
1973	23,635	1,990	144	8.4	0.6
1974	25,200	1,615	115	6,4	0.5
1975	26,135	1,758	110	6.7	0.4
1976	28,392	2,073	158	7.3	0.6
1977	27,682	1,939	167	7.0	0.6
1978	26,854	2,297	214	8.6	0.8
1979	24,257	2,405	215	9.9	0.9
1980	24,057	2,064	220	8.6	0.9
1981	24,460	1,743	252	7.1	1.0
1982	24,732	1,939	305	7.8	1.2
1983	25,468	1,931	312	7.6	1.2
1984	25,746	1,823	376	7.1	1.5
1985	26,154	2,068	379	7.9	1.5

Note: Includes products converted to carcass weight equivalent. Edible offals are not part of the carcass and therefore not included.

Source: Gee and Madsen (1988). Data from USDA Economic Research Service, Livestock and Meat Statistics 1983, Statistical Bulletin 715, and Food Consumption, Prices and Expenditures. 1985. Statistical Bulletin 749.



NOTE.--Oceania = Australia, New Zealand, South Pacific Islands. NA, SA = North and South America.

Source: USDA (1961-1984)

Figure 42.—Annual beef and veal production by world regions, 1961-1984.

become more widespread, with approximately 25% of the total world meat exports heavily subsidized.

International beef and veal production will not soon see the expansive growth of the 1970s (Food and Agriculture Organization 1983). Rising demand from population growth or increased income levels in developing countries will stimulate meat production through intensive poultry and pig production, or rural and pasture-based ruminant production (beef, sheep, goats) in countries such as Asia, Africa and Latin America. Pig meat recently has replaced bovine meat as the principal meat worldwide, however the fast growth in poultry production may change that picture in the future (Food and Agriculture Organization 1983).

Projections by the Food and Agriculture Organization suggested that the world consumption of meat will grow only 1% a year in the 1980s, with the demand in bovine meat (beef) growing only 0.7% annually. Extending projections to 2000, Resources for the Future indicated an annual rate of increase in total demand (domestic plus net trade) for all meats to be 2.4% globally over the 1980-2000 period, a drop from the 3.1% increase during 1969-80 (Sanderson 1984). The implication to international meat trade is a slow growth overall or decline in growth for some meat products (Food and Agriculture Organization 1983). Many developing countries are moving toward self-sufficiency in poultry and pig production. Trade in meat from ruminant animals may increase in the Near East and North Africa, but favoring neighboring suppliers in Asia and East Africa (Food and Agriculture Organization 1983). The implication to the United States meat industries is that there is little likelihood of the international trade improving over the next 20 years (Sanderson 1984). Thus, demand for meat in the United States will be primarily a function of domestic demands.

Consumer Demand for Meat in the United States

Meat Consumption

Total per capita meat consumption increased slightly from 1965 to 1985 (fig. 43). Beef surpassed pork consumption in 1953 (Nalivka et al. 1986) and steadily increased to a peak of 89 pounds per capita (edible weight[14]) in 1976 (fig. 43). Thereafter, beef consumption declined to a low of 76.5 pounds in 1980 and has since remained below 80 pounds. Lamb and mutton consumption was greater than 3 pounds per capita before 1960 (Stucker and Parham 1984). Consumption declined from 2.6 pounds (edible weight) in 1970 to 1.1 pounds by 1986, a very small amount compared with a total beef, veal, pork, lamb and mutton per capita consumption of 120.5 pounds.

The largest increases in per capita consumption were associated with poultry and fish (fig. 43). Consumption of chicken rose from 23 pounds in 1965 to 39.7 pounds (edible weight) in 1985. Turkey consumption nearly doubled in the same time period (USDA Economic Research Service 1986). The advances in harvesting technology increased the accessibility of fresh fish, and consumption rose from 10.8 pounds in 1965 to 14.5 pounds in 1985. Indications are that fish consumption will continue to increase (Blaylock and Smallwood 1986).

Studies on the composition of food supply in the United States have indicated a rise in the consumption of low-fat animal products, such as low-fat milk and fish, but an increase in the use of high-fat food such as hard processed cheese and baking and frying fats of both vegetable and animal origin. Dietary survey data and supermarket sales suggested that the fastest growing food items were meat mixtures, where meat, poultry, or fish are mixed with grains or pasta (National Research Council, Committee on Technological Options to Improve the Nutritional Attributes of Animal Products 1988).

Population Size and Age Distribution

Population growth alone increases the total consumption of meat. The population growth rate in the United States peaked in 1950-55 at 2.1% annually. Growth during the 1970s was 1.1% annually. Future increases in population growth are estimated to decline from annual rates of 1.0% to 0.2% by 2040 (Darr in press).

Changes in the age class distribution with the overall increase in the median age will affect the per capita consumption of meat. The age class distribution is shifting to middle and older groups, and older persons are not inclined to consume as much meat as younger individuals (Blaylock and Smallwood 1986). Food spending patterns differ across age classes also. Younger individuals are forming eating patterns relying on fast

[14]*Edible weight is used in comparing meat consumption across type of eat. Edible weight (beef) = 0.698 times (carcass weight) (USDA Economic Research Service 1986).*

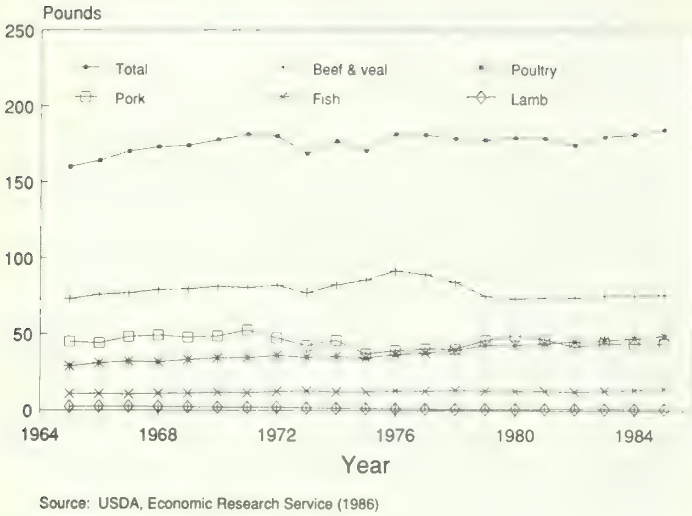


Figure 43.—Per capita meat consumption in the United States by edible weight.

food, more purchases away from home, and preferences for the lower priced cuts or even less meat consumption (Blaylock and Myers 1987, Gee and Madsen 1988). Regional differences in meat purchases tend to be small (Blaylock and Myers 1987).

Disposable Personal Income

Food competes for the consumer's dollar against nonfood items such as housing, clothes, cars, and recreation. Thus, the total budget allocation process must be analyzed in explaining meat consumption behavior (Haidacher et al. 1982). Studies in consumer spending patterns indicate that disposable income has significantly affected consumer spending patterns worldwide. Where disposable income is low, cereals make up a major portion of the diet. With increasing income, a wider variety of foods, including more meat, are eaten (Blaylock and Smallwood 1986, Food and Agriculture Organization 1983). Per capita disposable income in the United States has been higher than other parts of the world, and the high percentage of meat and poultry in the average American diet (over 33%) reflects this economic situation.

In the United States, consumption patterns are being established under a situation of rising nonfood costs and an availability of cheap food. As food costs as a whole increase, consumers tend to consume lower cost food products. Because beef is a major component of the food purchased and is relatively expensive, the amount of beef purchased tends to be reduced before that of many other foods when income is reduced (Gee and Madsen 1988). Before 1980, rising per capita disposable income levels were associated with rising per capita meat consumption. After 1980, per capita disposable income has continued to rise but the percentage spent on beef has declined. Per capita disposable income (1982 constant dollars) has increased from $9,829 in 1980 to $10,947 in 1986, whereas the percent spent on beef has fallen continuously from 2.4% in 1979 to 1.5% in 1986.

When individual income groups are analyzed, increases in meat consumption are still occurring within lower income groups, but the increases are not great in higher income groups. Thus, changes in the distribution of incomes will change the consumption of meat more than an increase in the average per capita income across the nation (Buse 1986).

Prices and Marketing Strategies

The cause for recent shifts and declines in per capita meat consumption is uncertain. Changes in sociological factors such as a more health conscious public or taste preferences, or changes in economic factors such as increased disposable income have been suggested as reasons for the shifts in consumer demand (Breidenstein 1988, Doane's Agricultural Report 1987, Drabenstott and Duncan 1982, Greenhouse 1986, Walter 1985). The hypotheses require numerous observations before these factors can be quantified econometrically (Crom 1984) and many studies have been and are being conducted to determine if structural changes have occurred in the demand for meat (Braschler 1983, Chavas 1983, Conway et al. 1987, Dahlgran 1987, Haidacher et al. 1982, Kokoski 1986, Moschini and Meilke 1984, Wohlgenant 1985).

Record high levels of meat production have placed a large and diverse amount of meat in the supermarket case. Beef demand is impacted by the availability of substitute products at lower prices than beef (Greenhouse 1986). Cost efficiencies resulting from the integration of production and processing activities have given a competitive advantage to poultry production that beef and lamb producers have not enjoyed. Not only is the conversion of feed more efficient in poultry than in cattle, but improved production technologies such as disease control, feeding practices, and confinement housing have allowed poultry production to maintain lower prices than beef (fig. 44). In the absence of such technologies, the retail price for chicken would have been 175% higher than the actual price in 1983 (Lipton 1986). In 1960, beef prices were twice chicken prices and by 1986 had risen to over three times chicken prices (fig. 44).

The continued ability of retailers to maintain profit from beef reflects their great buying power (many different packers) and the diversity of meat products available. When beef prices rise, retailers can offer the lower-priced meat products, such as poultry, to satisfy consumer demand (Gee and Madsen 1988). Packers and processors have developed brand lines of meat to reduce the ease with which a retailer can switch to alternative suppliers and have increased promotion efforts toward consumers to reduce the attractiveness of substituting other meats for beef. Although the results of these efforts will not be known for some time (Cohn et al. 1987), it is clear that meat production and marketing is highly competitive.

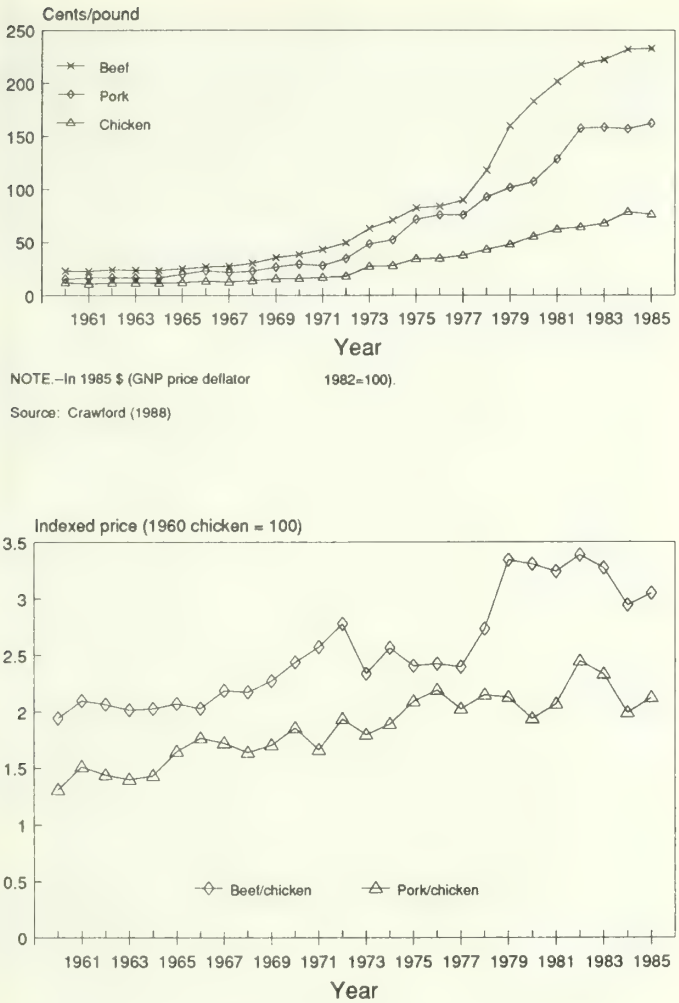


Figure 44.—Retail and indexed prices for whole chickens, pork, and choice beef, 1960-1985.

New product development in the meat industry has been spurred by the changes taking place in society. Working couples and single heads of households are attracted to convenience foods with short preparation time. In addition, increased amounts of food are being consumed away from home. In 1962, 28% of total food expenditures were spent eating away from home, and by 1985, the percentage had risen to 43%; fast food outlets cornered an increasing share of food expenditures (Lipton 1986). Concern about nutrition and health have raised additional issues about diet. Demographic changes in the population also are spurring new product development.

New poultry products developed to meet the changing wants and needs of consumers have helped to maintain the high demand for poultry. In the 1950s, shoppers would likely have purchased a store-labeled whole chicken. In the 1980s, consumers can select from various brand-name chickens, whole or cut-up chicken, boneless chicken or chunks, or pre-cooked items, such as barbecue turkey (Lipton 1986). Higher production costs have limited the new product development in the pork industry, although many new pork products have been developed (Gee and Madsen 1988). The relatively high consumer demand that beef has enjoyed for nearly 30 years has not exerted much pressure for new product development.

Boxed beef represents the last major innovation in the beef industry (Gee and Madsen 1988). Before this development 20 years ago, beef left the packer as sections of the animal, forequarters and hindquarters. Now beef is cut up into smaller portions called primal or subprimal cuts, sealed in vacuum-pack bags, and shipped out in cardboard boxes, hence the name boxed beef. In 1979, total packer boxed beef was 50% of fed cattle marketings, but by 1984, had increased to 77% (Gee and Madsen 1988). With the development of boxed beef, the slaughtering and packing of animals became assembly-line tasks and the average number of carcasses handled increased from 125 to 400 a day (Greenhouse 1986). But this innovation, a major step in increased efficiency of beef production, did not alter the end product provided to consumers.

Recently developed beef products have included prepackaged meat portions, precooked products, boneless cuts, and shredded beef with sauces (Gee and Madsen 1988, Greenhouse 1986). Perhaps the most encouraging recent development is the ability to restructure beef into fabricated steaks from high quality trimmings, much like the fabricated crabmeat now available (Gee and Madsen 1988). The beef fabrication process, developed at Colorado State University (Best 1986), would allow for uniform construction and fat content of each cut. The resultant product appears like a steak cut from the side of an animal. The Food and Drug Administration and the U.S. Department of Agriculture must approve the process before it can be used on a commercial basis.

Another production and marketing strategy being developed within the beef industry is the use of brand names, similar to brand development in chicken. This development is occurring for larger packing companies, for smaller livestock operations, and in Europe as well as in the United States (Geoghegan 1987, Greenhouse 1986, Howard 1987). Characteristics promoted include low fat, low cholesterol, production free from unsafe residues or chemicals, and taste (Greenhouse 1986, Howard 1987, Jackson 1985). In addition, the benefits of wild game meat are also being promoted as low in fat and cholesterol (Sheram 1986).

Projecting Meat Demand and Implications for Forage Demand

Short term projections indicate that demand for meat will be steady or will slowly rise (Walter 1985). Sanderson (1984), reporting on projections compiled by Resources for the Future, indicated a 0.9% growth in the total demand for meat (primarily domestic demand) in the United States, similar to the projected future population growth (Darr in press). This total demand for meat is less than the 1.4% annual increase witnessed during the 1970s. A work group consensus, at the Future

Agricultural Technology and Resource Conservation symposium (Smith 1984), was that beef per capita consumption would increase only slightly from 1984 to 2030 (table 27). This slow increase in per capita consumption suggests that increased demand for meat production will be primarily a function of population growth. The meat and beef industries have been characterized as "mature" industries, and growth in demand for mature industries is dependent entirely upon population growth (Fedkiw 1987).

In assessing the likely future trends in food consumption, Blaylock and Smallwood (1986) suggested that food groups likely to increase most were food away from home, fish, fresh fruits, and alcoholic beverages. Less than 40% of the total beef purchases are made away from home (Baker and Duewer 1983, Buse 1986). Beef is a small percentage of food purchased at restaurants and a much larger percent of food purchased for home (Thurman 1986). Thus, increases in beef seen as a result of increases in food purchases away from home will be smaller.

The cause for recent shifts and declines in per capita meat consumption is uncertain. Changes in sociological factors such as a more health conscious public, or economic factors such as record high levels of meat production will require a few years of data before shifts in consumer demand are quantified. For this assessment, population and income projections will be used to determine the future demand for meat production.

Forage demand could be greater if the lean beef production required only forage to finish animals. The recent trends are for a shorter period in the feedlot and not necessarily a longer period on grass. This would imply less grain demand rather than an increased forage demand. If per capita beef consumption increased and the increase was toward lean meat, then the forage demand would be greater to meet increased production of beef and lamb meat.

FORAGE AS AN INPUT TO ENERGY PRODUCTION

Projections made in the present assessment are based on the assumption that historical trends will continue to shape the future supply/demand and that changes in resource demand and land use will be an outgrowth of these trends and not abrupt discontinuities from the past. The possibility exists for a significant departure from historical trends. Two events that may dramatically alter the future management and use of forage resources are climatic change (Chapter 2) and the development of an energy industry using forage biomass as a feedstock.

Technological barriers and a significant drop in oil prices decreased the interest in biofuels generated during the 1970s oil crisis. Renewed interest will depend on (1) the cost and availability of oil, (2) the potential for replacing oil with coal, (3) developments in biomass conversion technologies, and (4) the availability of biomass (Byington 1988). Uncertainty exists within each of these areas. Adequate oil supplies are expected for another 30 years, although political factors and the desire to remain energy independent could raise oil prices through import duties and taxes (Byington 1988). Coal's high energy content per volume, concentration in major deposits, and vast reserves are balanced by high conversion costs and environmental considerations.

The advantages of biomass as an energy source are that biomass is a renewable resource, and converts with relatively few adverse environmental impacts when perennial vegetation is used. Limitations on biomass utilization are that it is a highly dispersed resource, is bulky, and has a relatively high water content. Although the conversion of biomass to ethanol has the advantage in that the end product is a usable energy product, the current economic feasibility of forage as a biofuel is still lacking (Byington 1988).

Byington (1988) presented a scenario regarding the future of biofuels and forage resources. Spurred by issues

Table 27.—Per capita consumption (pounds per person) in 1984, and estimated for 2000, and 2030.

Item	1984		2000		2030	
	Retail wt.	Carcass wt.	Retail wt.	Carcass wt.	Retail wt.	Carcass wt.
Beef	77	104	80	108	80	108
Veal	2	2	2	2	2	2
Pork	60	65	60	65	60	65
Lamb	2	3	2	3	2	3
Dairy products	540		520		510	
Chicken						
broilers	49		55		55	
mature chickens	3		3		3	
Turkey	11		13		15	
Eggs	36		33		30	
Fish	13		18		27	

Source: Smith (1984).

such as balance of payments, national security, idle cropland, and environmental concerns about climate change, the development of a forage biofuel industry is given government incentives such as: (1) laws mandating biofuel use, particularly in urban areas for environmental reasons, (2) government vehicle fleet use of biofuels, (3) tax breaks, (4) low-cost financing, (5) technical assistance, (6) price supports, and (7) increasing fossil fuel prices through taxes. Oil reserves are depleted in 30 years, and liquid fuels from coal become the least expensive fuel source. Biofuel development continues and eventually environmental concerns about coal and possible economic advantages over coal shift energy use to biofuels.

Under this scenario, a biofuels industry based on forage could create a new demand for land producing herbaceous material. The short-term impact on forage-producing lands will be marginal as cropland is used to supply this new demand. The long-term impact could be significant as cropland shifts back into crop production and an expanding beef herd and biofuel industry cause an intensification of management on pasture lands. Higher returns would shift land use from forage to biofuel production; livestock grazing would be eliminated on productive pasture and grazing lands where haying is possible. Substantial pasture and rangeland area in the South could be taken out of livestock production. Specific needs in regional livestock industries, such as supplemental feed in the northern regions, or land use patterns where only small blocks of hayland are available, would restrict the conversion of all grazinglands to biofuel production (Byington 1988). Grazing would remain on forested land in the South, range and pasture lands in the West, and land with no cropland conversion potential. Byington (1988) concluded that adequate forage supplies for livestock in 2040 would become unlikely if an expanded demand for cropland or forages developed.

SUMMARY

Forage is an intermediate good to the production of the final output, such as wildlife, livestock, wild horses and burros. The demand for the final output, the herbivore, can be used to derive the future demand for range forage. The demand for livestock is a function of society's demand for market commodities such as meat, hides, wool, tallow, and secondary products. The most significant demand for livestock is meat.

The demand for meat is a function of export demand and United States consumption. United States meat exports were less than 1.5% of the total meat supplies in 1985. The international meat trade is projected to grow slowly, with many countries seeking self-sufficiency in meat production. The implication is that the demand for meat in the United States will be primarily a function of domestic consumption. The domestic demand for beef or lamb meat is related to consumer tastes and preferences, disposable income, changes in human population size and age distribution, and the relative prices of alternative foods, particularly other meats.

The cause for recent shifts and declines in per capita meat consumption is uncertain. Changes in sociological factors such as a more health conscious public, or economic factors such as record high levels of meat production will require a few years of data before shifts in consumer demand are quantified. Population and income projections will determine the future demand for meat production.

The supply of meat is determined by the cost structure of production. The price of beef cattle or sheep depends upon the interactions between the supply and the demand of meat. The forage demand for livestock production depends on the technology associated with livestock production, the prices of alternative feeds, the interactions of forage with other inputs, and the price of livestock. The availability of grazed forages is critical in two segments of the beef cattle industry: breeding herds and stocker cattle production. For the sheep industry, the breeding herds are dependent upon grazed roughages.

Grazed forage consumed by beef cattle and sheep is produced on deeded nonirrigated rangeland and pasture, publicly-owned grazing land, deeded irrigated pasture, and from crop residue. The relative contribution of each forage source reflects the type of operation, type of animal, and the regional land use. Public grazing is more important in the West, whereas crop residue is more important in the East.

Forage demand could be greater if the lean beef production required only forage to finish animals. The recent trends are for a shorter period in the feedlot, which would imply less grain demand, rather than an increased forage demand. If per capita beef consumption increased and the increase was toward lean meat, then the forage demand would be greater to meet the increased production of beef and lamb meat.

CHAPTER 4: FORAGE SUPPLY/DEMAND PROJECTIONS

For the present assessment, forage supply was projected from the future availability of grazingland and likely improvements in forage production. Demand for grazed roughages was determined from future livestock projections, and assumptions concerning the future distribution of forage sources. Many of the aspects about the production and consumption of forage prohibit a traditional market equilibrium model at the national level (as is used for timber). Factors affecting supply and demand of forage are often local and reflect an individual livestock enterprise (Chapters 2 and 3).

The supply/demand of livestock has been simulated in econometric models where livestock production interacts with other agricultural commodities (Boss et al. 1978). The projection horizon is a function of factors included in the model that determine the supply/demand of livestock. When meat production is represented by changes in livestock inventories and animal prices, the model is often used to project for short periods of time, 1 to 10 years. Long-term issues, such as the impact of land availability, technological improvement in the forage production, and the effect of this improvement on inventories of livestock, can not be examined in many of these short-term projection models (Salathe et al. 1982, Taylor and Beattie 1982). The National Interregional Resource and Agricultural Production model (NIRAP) analyzes meat production as a function of feed inputs aggregated at the national level (Quinby in press). By incorporating some aspects of the livestock production process, this model provides a long-term projection for meat production and has been used in previous assessments and appraisals (USDA Forest Service 1980, USDA Soil Conservation Service 1987c). The NIRAP model was used to project the national demand for meat and livestock production for the present assessment.

All projections of the future rest on a set of assumptions concerning the demographic and economic variables within society. The basic assumptions for the Range Assessment projections are presented in this chapter, followed by the supply and demand projections for forage.

BASIC ASSUMPTIONS

Population

In 1986, the United States population was 242 million, an increase of 100 million in the previous five decades. Over the next five decades, population growth will be slower than in the last 50 years, and the population is projected to reach 333 million by 2040. The decline in the annual growth rate, from about 1.1% in the 1970s to 0.2% in the 2030-2040 decade, reflects assumptions about declining fertility rates (Darr in press). These population projections assume a net immigration of 750,000 people per year, including an estimate for net illegal immigration.

The distribution of population growth will influence the demands and services needed within states and regions. The most rapid growth will occur in the Pacific Coast, the Southern, and some areas within the Rocky Mountain region. The age distribution of the United States population will shift during the projection period to a greater proportion of the population in the middle-age classes.

Per Capita Disposable Income

Disposable personal income is that income available for spending or saving. As such, this income is related to the general economic picture often described by the gross national product (GNP). In 1986, the GNP was more than five times the 1929 level. Analyses by Wharton Econometric Forecasting Associates indicated that by 2040, GNP will increase over four times that of the 1985 level (Darr in press). Within this economic environment, by 2040 disposable personal income will increase some 2.5 times the level of 1986 (Darr in press). This increase in per capita income implies that future populations will have a much greater purchasing power than today. Although this is critical in terms of the consumption of goods and services, the link between disposable personal income and the consumption of meat, as discussed in Chapter 3, has weakened. Increased personal income will also have impacts on other uses of the range resources, such as recreation.

Energy

The economic projections assume that while transportation, trade, and other services will grow slowly in terms of their share of the total economic activity, the United States will continue to produce large quantities of physical goods in the manufacturing and construction sectors. Thus large supplies of energy, minerals, and other raw materials will be needed to produce these goods. Oil prices (in constant 1982 dollars) rise from $12 per barrel in 1986 to $50 in 2020 and remain at this level through 2040 (Darr in press). For this assessment, conservation and development of alternative energy sources slow the rate of increase in energy prices. The 2020-2040 prices are assumed to be high enough to stimulate the development of alternative energy sources with implications for the demand for timber and timber products, especially fuelwood. For forages, government intervention is

assumed necessary to foster an energy industry utilizing forages as an input to energy production (Byington 1988). Thus, the development of alternative energy sources is not assumed to shift the demand for forages.

Institutional and Technological Change

Institutional changes, such as legislation for the reservation of land for wilderness, parks, and wildlife refuges, have occurred in the past, and have changed the use of rangelands (fig. 23). Legislation has affected the management of rangelands in terms of providing forage and habitat for wild horses and burros, endangered or threatened plant or animal species, and wildlife (table 13). Technological changes have also impacted the production of forage (tables 11, 12, and 23). These institutional and technological changes are assumed to continue in the future and the effects of these changes will likely be similar to those that have occurred in the past. Many of these changes are implicit in the historical data used in preparing the projections. Other assumptions are explicitly described in the analysis.

Productivity within the Agricultural Sector

Productivity of the agricultural sector is expected to grow at 1.6% per year, with increased productivity of feed grains averaging 1.7% in 1990-2000 and 1.2% in 2000-30 (Quinby 1985). Increased productivity of rangeland is projected to grow at 0.7% per year (Pendleton and Hetzel 1983). This increase is based on the assumption that rangeland productivity would grow at this rate if the currently available technologies were implemented on the Nation's rangeland. Technology currently available to increase rangeland productivity includes undesirable plant and insect control, interseeding, fertilization, and improved animal management through grazing systems and fencing (tables 11, 12, 24, and 25). The factor most severely limiting increased productivity on rangelands is capital investments, including short-term investments for maintenance of productivity. Under an unfavorable economic situation, this annual increase could drop to 0.3%. A high demand for range products could increase the price received for those products. This return would enable and encourage the producer to make greater than expected capital investments in range improvements such that the annual increase could rise to 1.2% (Pendleton and Hetzel 1983). For this assessment, the median estimate was used to project likely future increases in forage production. This projection does not include the likely increases in beef and lamb productivity (table 25), nor does it include additional developments not currently available for forage production (table 12).

Trade Assumptions

A number of studies have projected that future world agricultural trade will likely grow more than in 1982-83 but less than in the boom years of the 1970s (Food and Agriculture Organization 1983, Quinby 1985, Sanderson 1984). Several factors will limit exports: increased production in foreign importing countries, debt problems in many developing countries, volatility in currency exchange rates, and less than robust foreign economic growth. For this assessment, United States export growth is expected to grow 3% per year in the 1990s and 2% over the following decade; the strongest growth will be in the export demand for feed grains (Quinby 1985).

Rising demand from population growth or increased income levels will stimulate meat production worldwide. The demand for this meat, however, will be met with intensive poultry and pig production, or rural and pasture-based ruminant production within each country. The implication to the United States meat industries is that the international trade in meat will probably not improve over the short-term. The demand for meat in the United States will be primarily a function of domestic demands, not rising exports.

Beef, Veal, Lamb, and Mutton Consumption

In 1950, per capita pork consumption was 64.4 pounds, beef and veal, 57.4 pounds, and poultry, 24.7 pounds (Lipton 1986). Thirty-five years later, beef and veal consumption (edible weight) was more than 80 pounds, poultry, 69 pounds; and pork, 62 pounds (fig. 43). By 1985, total meat consumption had risen 165% from 1950 levels (Lipton 1986). This rise in total meat consumption, primarily beef, was the basis for projections in the early 1980s that beef, veal, lamb, and mutton consumption would rise 11% by 2030 (USDA Forest Service 1980). Increases in meat consumption did not continue into the 1980s and by 1987, per capita meat consumption (beef, veal, lamb, mutton) had dropped below the high levels seen in the 1970's (fig. 43). Future projections suggested only a rise from 108 pounds in 1982 to 111 pounds (carcass weight) by 2030 (table 27) (USDA Soil Conservation Service 1987c). For this assessment, per capita consumption of beef and veal is assumed to remain at 110 pounds (carcass weight) and lamb and mutton at 2 pounds (carcass weight) in 1987-2040 (fig. 45).

DERIVED DEMAND FOR FORAGE

The demand for forage is a function of the demand for beef cattle and sheep. Incorporating the assumptions outlined above, supply/demand projections for beef, veal, lamb, and mutton were made with the NIRAP model. Factors affecting the demand for meat include future population levels, per capita food demands including meat, and net exports. Factors affecting the supply of meat include increases in crop productivity, feed grain production, and prices paid by farmers. An equilibrium solution of price-quantity combinations of agricultural products including meat was determined by the NIRAP model (Quinby 1987, Miranowski 1988). A national

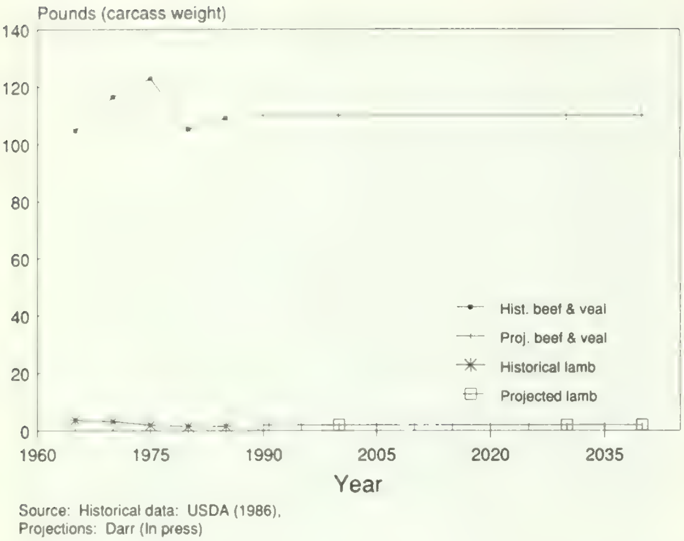


Figure 45.—Per capita consumption of beef, veal, and lamb: historical and projected, 1965-2040.

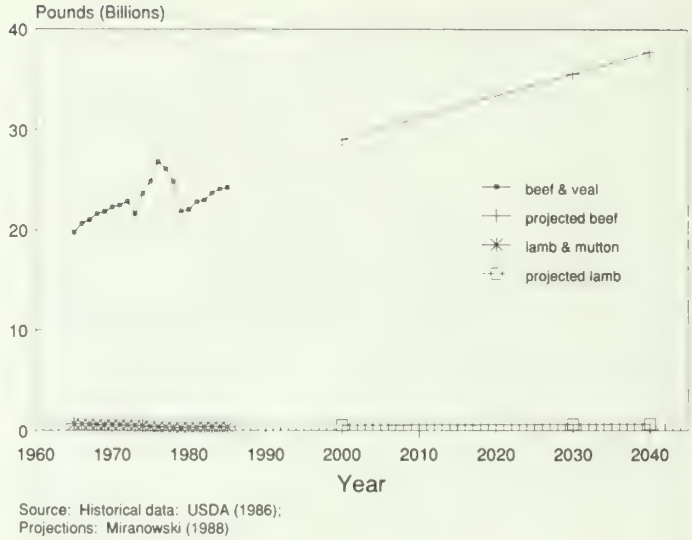


Figure 46.—U.S. meat production by animal type (carcass weight): historical (1965-1985) and projected (2000-2040).

feed/meat production relation is used in the NIRAP model to calculate livestock production. The regional relations between forage sources, availability of land, and factors in forage production are not examined in the NIRAP model and for this assessment, projections of meat production from the NIRAP model were disaggregated to the regional level based on historical distributions of livestock (Chapter 3). The derived demand for forage, based on regional historical patterns of grazed forage consumption, was then determined.

Meat Projections

Beef and veal production is projected to increase throughout the projection period and by 2040 will be 56% above the 1985 levels (fig. 46). This increase in beef and veal production reflects the 39% increase in population, the 260% increase in per capita disposable personal income, a 4% increase in meat exports, and a 2% decrease in meat import (resulting in a greater demand on domestic production) over the projection period. The 1985 base year value for per capita consumption of beef and veal was 109.1 pounds, thus per capita consumption rose slightly over the projection period. This per capita rise and population growth resulted in a 147% rise in the demand for meat. The effect of per capita disposable income on meat consumption is less than during the 1970s, but the significant rise in per capita income in the last projection period results in beef consumption slightly above 110 pounds. Even with these projected increases, beef and veal production do not exceed historical production values until 2000 (fig. 46).

Lamb and mutton production is a small component of the total meat production in the United States and as such, is difficult to project with any certainty. Projections from the NIRAP model suggest a very optimistic picture for lamb and mutton production with increases of 85% over the projection period to 660 million pounds by 2040 (fig. 46). Actual production for 1985 was 357 million pounds (U.S. Department of Agriculture 1986). Sheep inventories and lamb and mutton consumption records suggest an historical decline and a recent flat trend in consumption (figs. 34 and 43). The variability of historical levels of sheep were used to bound the optimistic projection.

Livestock Inventory Projections

The NIRAP meat projections (fig. 46) were used to estimate future livestock inventories (Gee and Madsen 1988). The historical variability in livestock inventories in 1965-86 reflects technological and social changes in meat and livestock production, including cattle cycles. The assumption is made that these factors will continue to influence livestock production to the same extent in the future. The certainty with which a projection can be made decreases in time, thus the upper and lower limits for the projections of livestock inventories were computed using 1 standard deviation from the mean for 1990, and 3 standard deviations for 2030 and 2040 (Gee and Madsen 1988).

Beef cow inventories in 2040 are projected to be 55 million, a 56% increase over 1985 inventories (fig. 47). Beef cow numbers are not expected to exceed the historical peak until after 2000, and the 2040 inventory is only 21% above the 1975 peak. Based on the historical variability in livestock inventories, the upper bound for the 2040 projection was 64.5 million beef cows and the lower bound, 45.6 million cows. Given recent trends in per capita consumption of meat, an aging human population, a flat export demand, and competitive substitutes for beef, it is unlikely that the beef cow inventories will move toward the upper bound, and more likely these inventories will be between the projected and lower

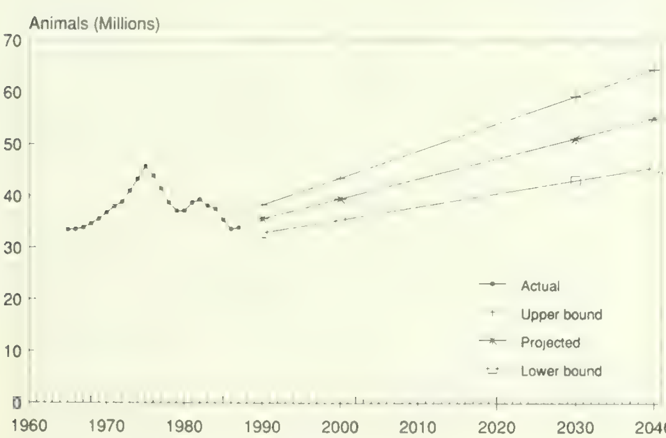
bound estimates (fig. 47). For this analysis, the projected inventory is used to determine the future forage demand from beef cattle.

Breeding ewe numbers were projected to be 18 million by 2040 or more than twice the 1985 inventory of 7.2 million (fig. 48). Although this projection is less than historical peaks (fig. 34), the decline in ewe numbers since 1965 would suggest that this projection is optimistic. The volatility of ewe numbers produces a wide upper and lower bound projection (fig. 48). Human population increases alone are insufficient to sustain a large increase in demand for lamb and mutton, and per capita consumption of lamb has declined (fig. 43). For this analysis, the lower bound will be used as the likely future for sheep inventory numbers and to determine the forage demand.

National Aggregate Forage Consumption Projections

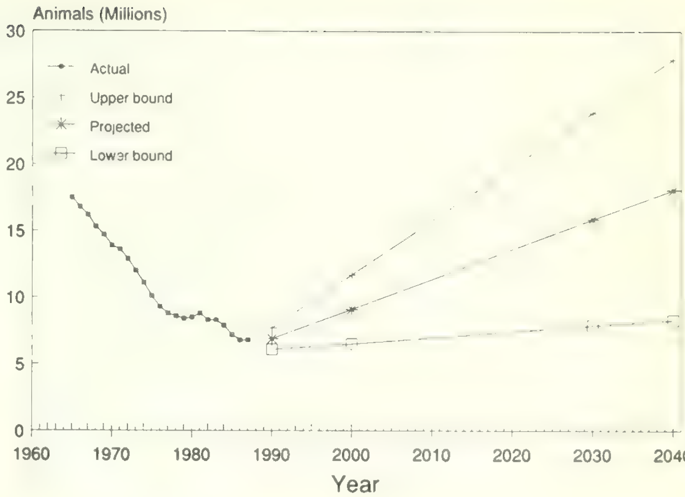
Aggregate grazed forage consumption was based on the above projected livestock numbers and an estimated per animal grazed forage demand from U.S. Department of Agriculture, Economic Research Service (ERS) budgets (Gee et al. 1986a, 1986b). Historical consumption of forage by beef cattle and sheep for 1980-87 and projections for 2000 through 2040 are shown in table 28. Upper and lower limits are based on the historical variability in livestock numbers (figs. 47 and 48). The upper and lower bounds of the forage demand projections for cattle differ from the mean (575.8 million AUMs) by 16%, whereas the upper and lower bounds for sheep forage demand are much greater at nearly 50% of the mean (35.5 million AUMs). This variability in livestock forage demand is a reflection of the decline in sheep numbers in 1965-85 and the variability in cattle numbers through two cattle cycles (fig. 34).

For this assessment, the projected future demand for forage by livestock is the sum of the projected demand



Source: Gee and Madsen (1988)

Figure 47.—January beef cow inventories (1965-87) and projection to 2040.



Source: Gee and Madsen (1988)

Figure 48.—January breeding ewe inventories (1965-87) and projections to 2040.

for cattle and the lower bound for sheep (total in table 28, fig. 49). These projected values reflect a slowly increasing demand for forage, driven by human population growth and, to a lesser degree, per capita consumption, exports, and imports. By 2040, total forage demand of 665 million AUMs represents an increase of 54% over the 1985 value for beef cattle and sheep (table 28). Based on this projection of demand, the forage supply would need to increase at least 1% annually.

These projections do not include other livestock, such as goats, horses, and hogs. The grazed forage demand for these livestock is small compared with beef cattle, and is assumed to remain small over the projection period. Wildlife projections are given in Flather and Hoekstra (in press) and the implications of this wildlife forage demand to range vegetation is discussed in Chapter 5 in the present report.

FORAGE SUPPLY

Supply projections for forage were based on the future availability of grazingland and the future technological improvements in forage production. The future land area needed for cropland and urban land are determined in the NIRAP model; the remaining land area is allocated to pasture, rangeland, and forest land based on historical trends. This land area projection for rangeland was then adjusted to account for the future implications of the Food Security Act. The likely future technological improvements were coupled with this land area projection to determine the future supply of forage.

Rangeland Area Projections

Projections made by the ERS indicate that pasture and rangeland area will increase slightly (1%) over the projection period (Miranowski 1988). The conversion of

Table 28.—Forage consumption for beef cattle and sheep (million AUMs) during 1980-87, and projections for 2000-40 in the United States.

Year	Beef Cattle			Sheep			Total
1980		434.0		20.4			454.4
1981		452.7		21.1			473.8
1982		460.9		19.9			480.8
1983		445.6		19.9			465.5
1984		438.5		19.0			457.5
1985		413.9		17.3			431.2
1986		392.8		16.3			409.1
1987		396.3		16.3			412.6
	Low	Projected	Upper	Low	Projected	Upper	Projected
2000	414.2	462.1	508.9	15.6	21.8	28.1	477.7
2030	504.3	599.0	693.8	19.0	38.2	57.4	618.0
2040	533.5	644.7	754.6	19.9	43.4	67.0	664.6

Source: Gee and Madsen (1988).

rangeland to cropland is assumed to be lower in the future than the extensive conversions of the 1970s. The future demand for cropland is assumed to be less because of reduced agricultural exports, increased growth efficiencies in feed grains, and increased feeding efficiencies in livestock. The increased production efficiencies will contribute to a decline in the acreage planted to feed grains and unplanted acres will return to a permanent cover of herbaceous vegetation. The decline in irrigated cropland, particularly in the West (Guldin in press, USDA Soil Conservation Service 1987c), also reduces the demand for conversion of rangeland to cropland in the future. These projections reflect the recent USDA Appraisal projections where future cropland used for crop production declines significantly (USDA Soil Conservation Service 1987c).

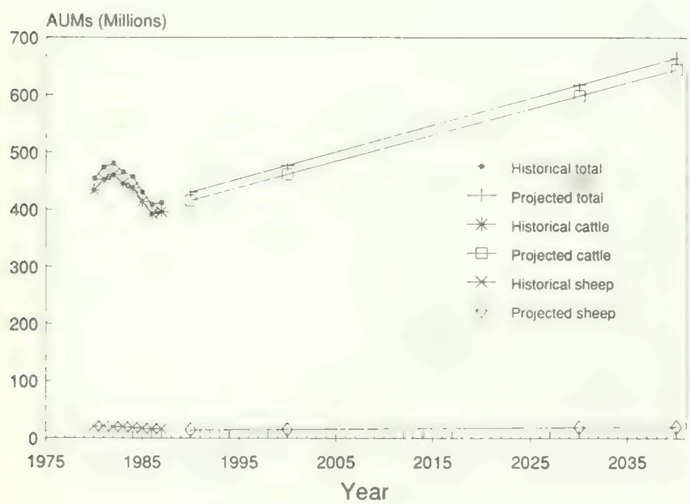


Figure 49.—Projected consumption of grazed forages by cattle and sheep, 1980-2040.

The ERS land area projections did not include any effect of the Food Security Act of 1985. The conservation provisions in this Act could potentially impact land use on cropland and rangeland. The "swampbuster" and "sodbuster" provisions of the 1985 Food Security Act are expected to slow the conversion of highly erodible rangeland to crop production. The conservation compliance provisions of the 1985 Food Security Act are also expected to reduce the conversion of highly erodible rangeland to cropland. The Conservation Reserve Program (CRP) will place nearly 45 million acres of cropland into permanent vegetation. About 85% of the acreage currently enrolled in the CRP has been planted to grasses (Dicks et al. 1988). At the end of this 10-year program, the vegetation cover on most of the western CRP lands will likely be native or introduced grass species. Over 65% of the grass plantings thus far have been tame (introduced) grass species. The CRP land planted to introduced grass species will probably remain in grass cover and be managed extensively. If fields seeded with grass species proceed through natural succession, range vegetation would be the likely vegetation type in the Rocky Mountain and Pacific Coast regions, and the states of Texas and Oklahoma in the Southern region. Because the future demand for cropland appears less than in the past, it is assumed that land placed in the CRP would not return to crop production.

In the western regions (Rocky Mountain, Pacific Coast, and the states of Texas and Oklahoma), it is assumed that by 2000, all CRP land will be managed as rangeland unless originally planted in trees. Western CRP lands planted to introduced grass are assumed to be managed as rangeland by 2000. From 2000 to 2040, this former set-aside land is assumed to remain in rangeland and be available for livestock grazing. In regions where forest is the climax and pasture is a viable economic alternative land use (Northern and Southern), the CRP land remains as pasture, unless originally planted into trees. At the national level, this land area projection represents a 5% increase in rangeland area from 1985 to 2040 (table 29).

The largest increases in rangeland area occur in the Rocky Mountain and Southern (Texas and Oklahoma) regions.

Increased Productivity from Technology

Productivity of rangeland was assumed to increase 0.7% per year during 1987-2040. Thus, by 2040, forage production per acre will have increased 47% over 1985 levels from the implementation of already developed technology.

Projections for Future Range Forage Production

Private Land

The supply of forage from private lands is the result of decisions made by individual enterprises. Those decisions rely on the availability and cost of land and technology. Based on the above projections for these inputs, the supply of forage from private lands in 2040 is projected to increase by 52% over the 1985 levels.

Public Land

Projections for the amount of grazing to be supplied from National Forest System (NFS) lands, given the current and projected demand, were obtained from USDA Forest Service, Regional Offices 1-9 (1987, 1988). Overall, AUMs permitted to graze on NFS lands are projected to drop in 1990 and then gradually rise slightly over the 1986 level by 2040 (table 30). These increases are greatest in the California region (Region 5) at 17%. Declines are projected for the Southwest (Region 3) and the Southern region (Region 8) (table 30). The amount of grazing to be supplied from the Bureau of Land Management (BLM)-administered lands will likely be a continuation of the current levels (Peterson 1988). Grazing on NFS and BLM-administered lands dominate the public forage supplies and projections of supplies from other public lands, such as state or local, are assumed to remain at

Table 29.—Rangeland area projections (1,000 acres) by assessment region.

Year	Rocky Mountain	Pacific Coast	Southern	Northern	Total U.S.
1985	413,396	240,775	115,754	426	770,351
2000	440,227	240,810	127,531	340	808,907
2010	439,382	241,751	128,335	290	809,758
2020	438,367	242,388	128,950	249	809,953
2030	437,346	243,148	129,517	220	810,232
2040	436,356	243,643	130,024	196	810,219

Source: 1985, Bones (1989), projections based on Miranowski (1988) and the assumption that cropland placed in the Conservation Reserve Program would remain in permanent cover.

Table 30.—National Forest System historical records (1980-1986) and future projections (2000-2040) for livestock grazing (1,000 AUMs).

Year	National Forest System Region[1]								Total
	1	2	3	4	5	6	8	9	
1980	1,408	2,157	2,330	2,307	544	719	225	67	9,757
1981	1,394	2,166	2,370	2,316	529	724	231	69	9,799
1982	1,393	2,172	2,428	2,288	567	745	229	80	9,902
1983	1,391	2,190	2,531	2,311	596	741	234	78	10,072
1984	1,401	2,214	2,513	2,252	608	741	247	77	10,063
1985	1,400	2,170	2,504	2,357	621	745	248	78	10,124
1986	1,400	2,151	2,510	2,355	592	748	239	78	10,073
2000	1,401	2,199	2,100	2,300	620	779	200	78	9,677
2010	1,406	2,290	2,120[2]	2,300	625	777[3]	200	78	9,796
2020	1,411	2,315	2,160	2,300	630	774	205	78	9,873
2030	1,425	2,335	2,200	2,300	655	774	210	78	9,977
2040	1,440	2,360	2,240	2,300	725	774	210	78	10,127

[1]*Assessment Regions correspond to the following National Forest System region: Northern Rocky Mountain, 1, 2, 4; Southwest, 3, California, 5; Pacific North, 6; Northern, 9; Southern, 8.*
[2]*Interpolation between 2000 and 2040.*
[3]*Interpolation between 2000 and 2020.*
Source: USDA Forest Service, Regional Offices 1-9 (1987, 1988).

current levels to 2040. The future supply of grazing from public lands will rise less than 1% by 2040.

SUPPLY/DEMAND COMPARISONS AT THE NATIONAL LEVEL

If forest and rangeland continue to contribute the same relative amount of forage to the total supply, then forage production on forest and rangelands will have to increase 54% by 2040 (fig. 50). This increase represents the demand on all sources of grazed forages (table 10). The area of rangeland is projected to increase by 5% by 2040 and the assumed technological increases in forage production result in a projected increase of 47% in forage supply. Thus forage supplies would appear to nearly meet the derived demand for forage (fig. 50).

The relatively flat projection for the supply of public grazing contrasts with the projected increase in forage demand (54%). Thus, in terms of total forage consumption, the relative contribution from public lands will decline. This projection implies that these additional forage demands, if met, will need to be supplied from the private sector. The amount of rangeland in the private sector is projected to increase by 5%. Much of this land will be former cropland where the productivity may be higher than the average for rangeland. Permanent plantings for the current set-aside programs, however, could have significant implications on the long-term supply of forage. In Oklahoma, native pasture produces only 50 pounds of beef per land unit whereas introduced pasture grasses produce 250 pounds of beef (Sims 1988a). Long-term maintenance costs of native versus tame pastures must also be considered. These forage differences will be critical in the determination of a land use offering the highest return on former CRP lands.

These supply/demand comparisons of forage are based on the demand for livestock production only and do not consider other range outputs that use forage, such as wildlife or wild horses and burros. A comparison of the future wildlife projections in western United States with these livestock projections is made in Chapter 5.

ALTERNATIVE SCENARIOS OF SUPPLY/DEMAND

Land Area Projections Based on Historical Trends

Historical forces affecting the use of rangeland have included: (1) demand for crop products; (2) withdrawal of land for recreational, wildlife, and environmental purposes; and (3) withdrawal of land for urban areas. Conversion of pasture and rangeland to other uses is not likely to increase dramatically in the future (O'Brien 1988). Future increases in crop productivity and declines in crop exports will result in a lower demand for cropland. The recent USDA Appraisal projects that cropland used for crop production will decline significantly in the future (USDA Soil Conservation Service 1987c). More than 350 million acres were in crop production in 1982, and by 2030, the Appraisal analysis suggests that only

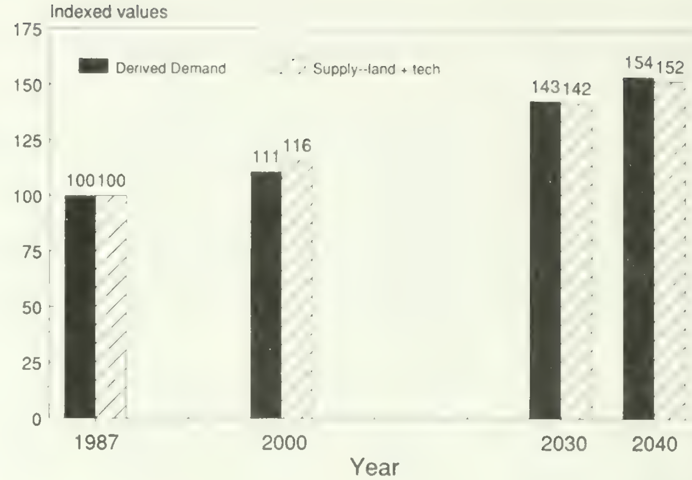


Figure 50.—Forage supply/demand projections indexed to 1987.

218 million acres will be needed to supply the crop production needs (USDA Soil Conservation Service 1987c). This analysis implies that potentially 152 million acres of cropland could sit idle, move into set-aside programs, or be converted to alternative land uses which bring a higher profit such as urban land.

The Appraisal projections were based on several assumptions concerning land use shifts (USDA Soil Conservation Service 1987c): (1) consumer demand for less meat and a leaner meat product will lower the demand for feed grains; (2) reduced exports place less demand for cropland; and (3) few conservation measures mitigate wind erosion, notably highest in the Great Plains. In the Appraisal analysis, cropland with the lowest profit per acre was identified as those acres which would be removed from crop production to reduce excess production and to meet the Conservation Compliance provisions in the Food Security Act of 1985. Sheet and rill erosion per acre is greater in regions other than the Great Plains, but attacking erosion by reducing acreage with the smallest profit margin per acre means that cropland comes out of production in areas such as the Great Plains. Less than 40% of the available cropland in the Great Plains is projected to be in production by the year 2000 (USDA Soil Conservation Service 1987c). Thus, the future uses of the projected idled cropland will depend on the alternative land uses available within each region.

Government crop-acreage control legislation has and will continue to have a significant impact on the use of rangelands. The long-term use of land in the most recent acreage-control program, the CRP, is uncertain. This land, if it remains in permanent vegetation cover, could increase forage supplies for wild and domestic herbivores. As assumed in the above land area projection, nearly 35 million acres from the CRP will remain in the grazingland base at the end of the program in 10 years. At the national level, the decline in pasture and rangeland area has been 0.33% per year over a period during

which cropland acres were in high demand (1969-1982).[15] Over the next 10 years, the historical loss of pasture and rangeland would mean a loss of 23 million acres. Thus, if the CRP acres (over 35 million acres) remained in grass and shrub cover, the national total of pasture and rangeland area would remain relatively unchanged for at least two decades into the projection period.[16] If rangeland area continued to be lost at the historical rate over the 1985-2040 projection period, and the CRP acres returned to cropland, the annual loss of rangeland would be 2.54 million acres and by 2040, the Nation's rangeland area would be 630 million acres, down from 770 million acres in 1985.

At the regional level, the current distribution of enrolled acres can be used to estimate the final distribution of CRP lands. The potential CRP enrollment acres in each region could be: Northern Rocky Mountain, 18.0 million; Southwest, 0.9 million; California, 0.3 million; Pacific North, 2.6 million; Northern, 8.8 million; and Southern, 12.4 million. If the historical annual losses of pasture and rangeland continued over the next 10 years, the following loss in total rangeland area by region would occur: Rocky Mountain (NR + SW), 12.0 million; Pacific Coast (PN + CA), 0.8 million; Northern, 9.2 million; and Southern, 1.5 million. Thus, in all Assessment regions, more land would be converted into permanent vegetation cover from CRP than would be removed from pasture and rangeland use over the same period. If the rapid land conversions of 1969-75 reoccurred, however, pasture and rangeland area in the Northern and Southern regions would decline. Historical data on regional conversions of forest grazing were unavailable.

Previous government set-aside programs have resulted in little acreage remaining in permanent cover. During periods of high crop prices that followed the set-aside programs, acres were plowed up and put back into crop production (Bartlett and Trock 1987). It is difficult to determine the future consequences of the entire Food Security Act of 1985.

Shifts in the Regional Supply of Forage

Regional forage consumption patterns differ across the United States. Forage from deeded non-irrigated land is the mainstay of livestock operations in the Southern and Northern regions whereas forage from a variety of sources is important in the western United States (table 18). The future supply of forage from public lands will affect the forage demand differently across the regions.

If the relative distribution of different forage types were to remain the same as the distribution in 1985 (table 18), all feed sources would need to expand by 40% or more to meet the projected demand in 2040 (table 31). Beef cow inventories at the historical peak in 1975 were 29% greater than the 1985 inventories, suggesting that the forage base has the ability to expand to meet a 29% increase in demand. Crop residues are currently in surplus, and economic incentives could overcome the management problems associated with the efficient use of this feed type (Gee and Madsen 1988). Expansion of irrigated pasture seems unlikely, because of rising costs of water and increased demand for water by urban areas. The historical trends in permitted grazing on public lands suggests slight or steady declines in grazing. These possible shifts in terms of the distribution of forage sources, if the expected demand is to be met, will differ by region.

Shifts in the regional supply of forage were analyzed with the following assumptions about the future distribution of forage: (1) a decline in grazed forage from public lands (NFS and BLM), based on trends during the last 10 to 15 years[17] (Gee and Madsen 1988); (2) irrigated grazing not expanding beyond 1985 levels; and (3) grazing of crop residues not expanding beyond 1985 levels. Assumption 2 reflects the premise that further expansion of irrigated pasture would be at the expense of more profitable cash crops, and the future costs of producing irrigated pasture will probably rise in relation to increasing water costs. Because water supplies are increasingly being sought by urban areas in the arid west, irrigation water supplies will continue to decrease, and shift agricultural water to only the most profitable crops. Assumption 3 is based on the premise that although many acres of crop residue go unused annually, the location and lack of fencing and water raise practical concerns in using this source of feed (Gee and Madsen 1988).

Under these assumptions, several feed sources decline in their relative contribution to the total forage, placing a greater demand for forage from deeded pastures (table 31). By 2040, irrigated grazing and crop residue are supplying the same amount of forage as in 1985 and public grazing has declined to 34% of the 1985 level. Total forage demand has increased 54% over the 1985 levels. Thus, the contribution that deeded nonirrigated forage must make to the total forage supply would have to increase by 71% over the 1985 contribution to meet these expected demands.

SUMMARY

Projections presented in this chapter suggest that the supply of forages at the national level will nearly

[15]*Frey and Hexem (1985) reported 890 million acres in 1969 and 820 million acres in 1982 of grazingland—forest, pasture and range. This 70 million acre loss represents an annual loss of 0.6%, or 5.3 million acres. When only pasture and rangeland acres are examined, 692 million in 1969 and 662 million in 1982, the annual loss is 0.33% or 2.3 million acres per year.*

[16]*When the declines in forest grazing are included with pasture and rangeland, the annual decline in grazingland area is 5.3 million acres, and over 10 years, this represents a decline of 53 million acres in the grazingland base. Forest grazing, however, has declined for a number of reasons, including changing management practices which exclude livestock grazing. Thus, although the CRP land will return acres to forest land, changes in management on forest land could impact forest grazing much more significantly.*

[17]*Gee and Madsen (1988) reported that the decline in BLM grazing was nearly 5% per year during 1965-85 and was less than 0.2% on NFS lands at the national level. These are based on historical trends, not planning projections.*

Table 31.—Projected consumption of grazed forage (million AUMs) by type of forage, 2040, by assessment region in the United States.

Type of forage	NR	SW	CA	PN	SO	NO	Total
			Continuation of historical trends[1]				
Deeded grazing land							
Nonirrigated	157.8	10.3	33.4	31.2	280.0	72.4	585.1
Irrigated	6.7	0.2	4.7	6.7	1.2	—	19.5
Public grazing land	25.5	5.4	3.1	3.2	11.0	—	48.2
Crop residue	13.5	0.3	2.7	2.2	11.5	5.1	35.3
Total	203.5	16.2	43.9	43.3	303.7	77.5	688.1
			Reduced forage substitutes[2]				
Deeded grazing land							
Nonirrigated	181.8	12.3	40.1	39.9	290.7	72.6	637.4
Irrigated	4.2	0.2	1.9	2.2	0.8	—	9.3
Public grazing land	9.2	3.4	0.8	0.5	5.2	—	19.1
Crop residue	8.3	0.3	1.1	0.7	7.0	4.9	22.3
Total	203.5	16.2	43.9	43.3	303.7	77.5	688.1

[1]*Both analyses reflect the median projection for sheep and cattle.*

[2]*Projections based on the following assumptions: (1) Deeded nonirrigated rangeland is assumed to compensate for reductions in forage from different sources. (2) Supplies of public grazing land by 2030 are expected to drop an average of 82% below 1985 levels. This is based on projection of historical trends in AUMs for 1977-85 for FS and 1970-86 for BLM grazing. (3) It is assumed that there is no expansion in irrigated pasture production above 1985 levels. (4) It is assumed that crop residue consumption will stay at 1985 levels.*

Source: Gee and Madsen (1988).

meet the demand for grazed forages in 2040 if certain assumptions are met. The most critical of these assumptions is the continued increases in forage production on forest and rangelands, resulting from implementation of existing technology. Recent analyses of range improvement practices, as discussed in Chapter 3, suggest that an improved livestock market will be necessary for the assumed application of this technology to occur. A critical assumption on the demand side is the constant per capita consumption for beef, veal, lamb, and mutton. A decline in per capita demand will, consequently, cause a decline in the demand for grazed forages. In addition, a shift in preference for leaner meat may cause a shift in the relative contributions of feed in the livestock production process. As discussed in Chapter 3, this feed shift may increase forage demand.

Projections at the regional level suggest that shifts in the relative contribution of forages will occur. Most notably is the decline of the relative contribution of public grazing. This decline will necessitate increased forage production on private lands if the projected forage demand is to be met. Projections of increased rangeland in the private sector could contribute to an increased supply, but forage production must also increase on a per acre basis to meet this derived demand.

The subtle relations between land available for forage production, production factors within regions, and shifts in livestock productions between regions were not analyzed in this assessment. This analysis assumes that cropland conversions similar to the late 1970s will not result in a resurgence of "sodbusting." Nor is it assumed that urbanization will dramatically affect the national supply of rangeland.

CHAPTER 5: SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF SUPPLY/DEMAND COMPARISONS OF FORAGE

INTRODUCTION

Projections made in Chapter 4 imply certain social, economic, and environmental conditions in the future. The desirability of this future depends on society's values concerning the range resource. These values encompass social, economic, and environmental concerns of individuals and groups. As future changes in society's values cannot be foreseen, this discussion of the implications of the projections will necessarily be based on the values that society historically has held and currently holds for the use of rangelands. These historical and current trends will be used to project probable future trends in the values society assigns to the uses of rangeland. This examination of the likely future social, economic, and environmental conditions sets the stage for describing the obstacles and opportunities to managing rangelands (Chapter 6).

SOCIAL IMPLICATIONS

Social Implications Defined

Held values, ideas held by an individual about something, regulate preferences that function to assign relative value to objects (Brown and Manfredo 1987). Society's held values about the range resource can be categorized into cultural, societal, psychological, and physiological subcategories. Cultural values are ideas and thoughts that make up a culture (Brown and Manfredo 1987) and might be exemplified with respect to the range resource in the value of the livestock business as a way of life in the western United States (Bartlett 1986, Pope 1987). Societal values are defined in terms of social relationships among people. The community focus and the social dependence among western ranchers described by Erhlich (1985) are examples of societal values. Psychological values are related to the benefits that an individual perceives from the object of value (Brown and Manfredo 1987). Springtime hikes to see alpine flowers, birding trips to the grasslands, or knowing that bison or wild horses exist or that endangered plants have protected habitat reflect psychological values. And finally, physiological values may be associated with the range resource when interaction with the range resource through either work or recreation enhances health. Individuals might value the exercise associated with recreational hiking or horseback riding because of the health benefits, stress reduction, or a change of pace. The physical labor associated with operating a livestock enterprise might be valued because of its physiological benefits. Although the social value of range vegetation has not explicitly been determined, this value does influence the behavior of those who might use the land (Pope et al. 1984b). Society's ideas about the range resource regulate preferences that function to influence the use of rangeland.

Social Implications of Projections

The projected futures for range, wildlife, water, timber, and recreation imply increased demand for these resources and an increased use of forest and rangelands (Chapter 4 this assessment, Cordell in press, Flather and Hoekstra in press, Haynes in press). The public's increasing interest in water quality will focus attention on the management of rangeland (Guldin in press). The social benefits of the range resource may be jeopardized with increased use and intensification of use unless proper management is implemented.

Livestock enterprises and livestock grazing on rangelands will continue to contribute to the social well-being of rural communities. The future intensification of rangeland use will change ranching as a way of life. The increased need to maintain viable ranching operations by marketing additional products, such as different meat products, wildlife, or recreational opportunities, will increase the interaction between ranching operations and urban dwellers. More opportunities will likely exist for urban dwellers to experience the range resource. Cordell et al. (1983) projected that the demand for primitive, semi-primitive, and roaded natural and rural areas will outstrip future population growth. The value of wilderness or habitat for threatened and endangered species within a functioning ecosystem has increased with the passage of legislation such as the Wild Free-Roaming Horse and Burro Act of 1971, and the Endangered Species Act of 1973. This value is often held by people who may never experience the resource directly.

Social values influence the allocation of forage to wildlife, wild horses and burros, and livestock. Many different views exist concerning the use of rangelands by grazing animals. The extremes might be characterized by those who feel that all resource damage is linked to livestock grazing, and those who feel that rangelands should be managed for a single use, livestock grazing. Pressure exists to remove livestock from public lands. Recent concerns about chemicals in the environment have shifted the emphasis in vegetation management to biological control methods. The role that livestock have in vegetation management will be difficult to determine in an atmosphere demanding livestock removal from

public lands. The perception that rangeland health has deteriorated primarily from livestock grazing will be heightened in a future where demand for more wildlife habitat, wild horses and burro habitat, and threatened and endangered plant and animal species are cast up against increased livestock production on forest and rangelands.

ECONOMIC IMPLICATIONS

Economic Implications Defined

Economic implications are a special case of social implications and concern the monetary aspects of range forage production. Because it is difficult to assess the value of vegetation to uses such as wild horses and burros, or threatened and endangered species (Bartlett 1986), economic implications traditionally have been limited to a valuation of range forage for livestock. Forage for domestic grazing is valued on the site and at the margin (Bartlett 1986) and will vary with different enterprise structures. To provide sufficient information to compare other uses of forage, an understanding of the joint production of different animal species using the same resource base is necessary but little progress has been made toward this understanding. This situation is complicated further by uses such as the harvesting of native plants, so the plant, not an animal, is the product. Ultimately the monetary valuation of range vegetation to produce this diverse mix of outputs must be determined to examine resource tradeoffs. In the past, most of these uses were marginal, that is, did not determine the use of large areas of rangeland. In a future demanding more outputs from forest and rangelands, the economic valuation of different uses may determine rangeland use.

Economic Implications of Wildlife Use

The amount spent per hunter or fishermen for access to private lands has increased substantially since 1980 (fig. 51). On an annual basis, these increases vary from 7% for fishing to 12% for big game hunting. Access fees are a function of several factors including interpersonal relationships between the parties buying and selling the lease, the availability of game, services and facilities, and the general hunting experience. Although these factors make it difficult to precisely determine the value of wildlife, Pope and Stoll (1985) concluded in their study of Texas hunting access fees that the provision of services and facilities generally does not enhance the value of the hunting experience as much as access to a variety of game species on an adequately large parcel of land. Thus, this rise in access fees is an indication of an increase in the value of grazing in wildlife production. Although many success stories can be told on Texas rangeland, the viability of enterprises based on wildlife alone is still being explored. Unless future possibilities for economic returns from wildlife grazing increase, the

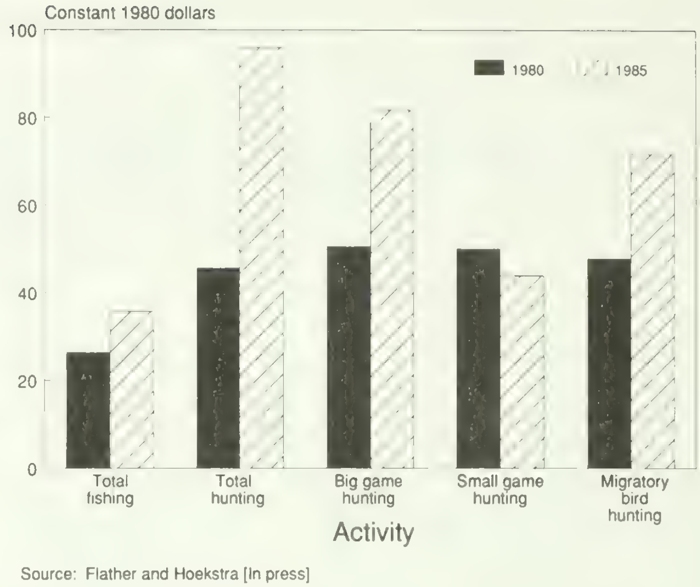


Figure 51.—Trend in private access fees (dollars per spender) for fishing and hunting, 1980, 1985.

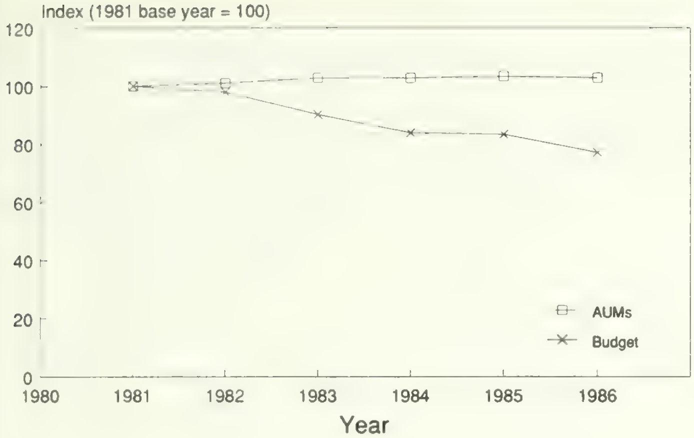
projected scenario implies a grazingland capable of supplying forage to livestock.

Economic Implications of Livestock Use

Improved range productivity, increased animal feeding efficiencies, and an increasing rangeland base contribute to an improved livestock industry in the future. Grazed forages remain at 80% to 90% of the total feed mix for livestock and it is unlikely that this relatively inexpensive source of feed will decline in the total feed mix in the future. Grazed forage is currently the cheapest source of feed and will likely remain inexpensive relative to other sources of feed. With the rangeland base increasing only 5% nationally, the projected forage supply relies on the implementation of currently available technology to meet the future demand for forage.

The distribution of sources for grazed forages will likely vary from historical patterns. Projections for Bureau of Land Management (BLM) permitted AUMs indicate a flat future supply, and projections for National Forest System (NFS) lands indicate a rise of less than 1% in permitted grazing (Chapter 4). The 1987 budget, in terms of constant dollars, for the NFS range management program has declined 22% since 1981. The number of AUMs authorized on NFS lands has remained nearly constant at around 10 million AUMs (fig. 52). The administration of these permits is only one responsibility of the range management program of NFS (USDA Forest Service 1987d).

Projected declines in irrigated lands will also impact the amount of pasture irrigated (Guldin in press, USDA Soil Conservation Service 1987c). The average area per grazing animal in western United States is lower than other parts of the United States (table 21) only because



NOTE.—Budget reported in constant 1981 dollars and is the net of inflation or deflation.

Source: Comanor (1988b)

Figure 52.—National Forest System range annual budget and authorized grazing use, 1981-1986.

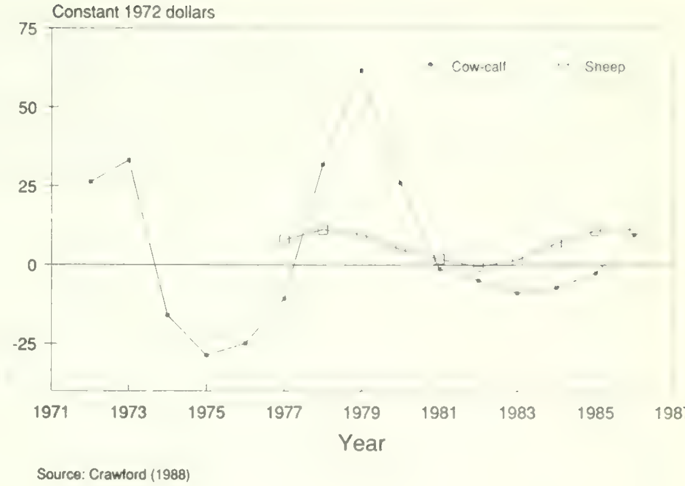


Figure 53.—Net returns on sheep and cow-calf operations: receipts less cash costs for 1972-1986.

of the high productivity of irrigated pasture and the accessibility of public grazing. Increasing costs of irrigating and the flat projected supply of federal grazing will result in herd reductions on those enterprises unable to implement necessary technology to improve forage production on their remaining land.

With the overall increase in forage demand, the decline in the relative share of public grazing and irrigated pasture implies that private lands will need to make up the difference in forage supply. Livestock operations unable to buy, grow, or otherwise obtain private forage for all seasons to replace public forage will not be part of the future growth in this industry. Thus, fewer livestock operations will be associated with public lands, with a potential decline in service industries associated with livestock production in these rural communities. This decline, however, is tied to social pressure to remove livestock from public lands, which is related to an increased demand for recreation and wildlife outputs. Services associated with recreation will likely increase in these rural communities.

At the state level, the future significance of this relative decline in federal forage can be seen in comparisons of the contribution that federal forage makes to the total feed mix within a livestock enterprise. Across the 13 western states, the median dependency level on federal forage is 23% (USDA Forest Service and USDI Bureau of Land Management 1986). In the southwestern states where animals can graze yearlong on federal lands, enterprises may get 36% (Nevada) to 44% (New Mexico) to 60% (Arizona) of their total feed from federal grazing. The northern Great Plains states depend on federal forage to supply from 11% (Montana) to 13% (Nebraska) of the total feed (USDA Forest Service and USDI Bureau of Land Management 1986). Amounts for other western states fall in between these examples. Even for livestock enterprises relying on federal forage for only 11% of the total feed mix, this amount may be difficult to replace as most of the enterprises utilizing federal forage would be in counties where most of the land would be managed by the federal government.

The recent volatility in beef cattle markets has spurred new approaches to diversifying a livestock operation (Heimlich and Langer 1988). Since 1975, livestock numbers have declined as the inventory adjusted to the relatively constant per capita demand for meat. The recent agricultural credit crisis has placed considerable stress on the livestock industry (Drabenstott and Duncan 1982). An estimate of the profitability of the beef cattle and sheep enterprises can be seen in cash receipts minus cash costs[18] (fig. 53). Profit volatility was very high for cow-calf operations in 1972-85. A profit has been made more often in sheep operations than in beef cattle since 1977 (fig. 53). Net cash returns for cattle operations were negative during 1981-84 when feed costs were high and cash receipts were low (Bowe 1987). When capital replacement costs are added into this equation, cattle operations were profitable only during 1978-80 over the entire 1977-86 period. In the past, cash shortfalls may have been weathered through rising land values or mineral income, but recent declines in land and mineral prices have resulted in financial losses to ranch operations (Bowe 1987).

Cash shortfalls imply an inability to sustain the necessary long-term improvement needed in a livestock operation. Recent indications show that range improvements have not been and are not being put in place (Gilliam 1984, Lewis and Engle 1982). The projected supply scenario from Chapter 4 assumes an annual increase in forage productivity of only 0.7%. The historical volatility in livestock production costs will affect the ability of ranch/farm operators to implement technology necessary

[18]*Source: Terry Crawford, unpublished data obtained from the USDA Economic Research Service cost of production survey.*

for long-term improvements in forage production. In the past, a diversity of incomes from rangeland was important to maintain cash flow and long-term improvements. The imperative to be efficient and to diversify in order to remain in the industry was seen in the early 1980s (Special Advisory Committee 1982) and this appraisal is likely to reflect successful management strategies for the future as well.

Recent diversifications in ranching have included bed and breakfast operations (Wyoming Farm Bureau 1987), recreational opportunities such as cross-country skiing (Freese and Coble 1988) and hunter lease agreements (White 1987); harvesting the seed or the plants of native species (Goodin and Northington 1985, Proulx 1984), tree nuts, wood chips or fuelwood; alternative meat products such as buffalo, and livestock products emphasizing nutritional quality or production without chemicals (Briney 1987, Cohn 1987, Zuckerman 1987). The economic value of the range resource will reflect these outputs. Although less than 1% of private grazing land is currently used primarily for wildlife or recreational activities (Heimlich and Langer 1988), land owners who charge access fees for recreation or hunting are more likely to implement range improvement practices (Lacey et al. 1988).

ENVIRONMENTAL IMPLICATIONS

Environmental Implications Defined

Environmental implications involve an assessment of the ability of the land to sustain long-term productivity of range vegetation. Capital, labor, and state-of-the-art technology influence the productive capacity of forest and rangelands.

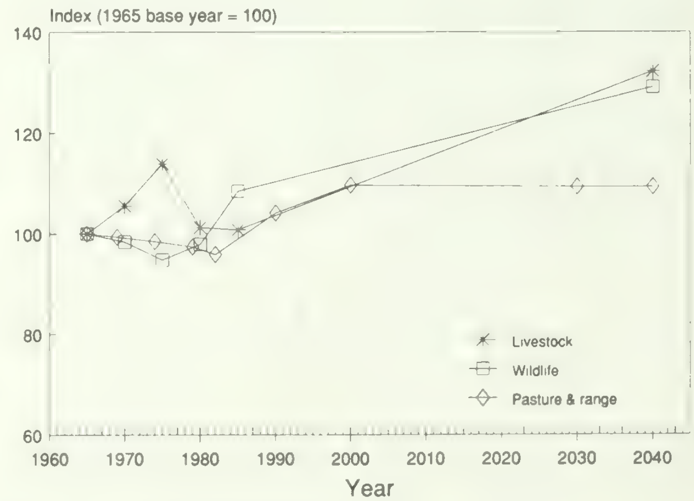
Environmental Implications of the Projections

The demand for meat, and consequently forage, are projected to be great enough to foster the implementation of technologies to sustain and enhance range productivity. Analyses explicitly linking the environmental and production processes and income objectives for either forage production or livestock production at the national level have not been developed. Economic theory would suggest that a strong demand for a product would strengthen the market for that product. The future scenario assumes an improved livestock market, and the consequent implementation of additional technologies to improve forage production. This future demand implies that management on rangelands will intensify.

The national projections for the supply and demand of range forage for livestock considered the potential impact of land use changes but these projections were made in isolation of the future supply/demand of other outputs, such as timber or wildlife. Multiresource interactions were examined in the regional case study discussed in Chapter 2 and for NFS lands at the national level by Hof and Baltic (1988). Those scenarios indicated an interaction between the production of timber, the production of forage, and to a greater degree, the production of wildlife.

Forest and rangeland supply food and habitat for both wildlife and livestock. A comparison of the projections for livestock grazing (from the present assessment) and wildlife grazing (from the Wildlife Assessment, Flather and Hoekstra in press) indicate a potential conflict (fig. 54). Big game numbers (elk, deer, and antelope) are projected to increase 19% by 2040 over 1985 inventories in the western United States. Livestock numbers are projected to increase 32% over the same period. Rangeland area is projected to increase only 5% by 2040 (fig. 54). The enhanced rangeland productivity is projected to meet only the increased forage demand for livestock. Even though domestic and wild grazers and browsers are often complementary users of rangeland and, thus, competition is not 100% temporally and spatially, grazing pressure from wildlife and livestock will increase in the future, beyond the projected supply. This intensive use of our Nation's ecosystems implies little likelihood that the condition of the vegetation or the productivity of the system will improve unless sufficient technology is implemented to enhance the productivity of these ecosystems.

Although enhancing rangeland productivity for livestock may increase the food and habitat for wildlife, some management intensifications for livestock may not necessarily improve the future wildlife situation. For example, the paddock cell layout associated with short duration grazing systems increases both human and domestic animal activity near the center of the cell where the water tank is often located. Some indications exist that wildlife avoid these highly congested areas, thus restricting wildlife access to water (Prasad and Guthery



NOTE.--12 of 15 western states reported.

Source: USDA (various years); Flather and Hoekstra [In press]

Figure 54.—Trends in livestock and wildlife AUMs and rangeland area in the western United States over historical (1965-1985) and projected periods (2000-2040).

1986). Even if the projected rising forage production were available to wildlife, this increase would not appear sufficient to meet demands from both domestic and wildlife grazing.

Obstacles and opportunities exist for allocating the grazing resource on rangelands. Economics and increasing regulation of agrochemicals have restricted the use of some improvement techniques. Previous overgrazing has left some range managers with degraded rangeland ecosystems. The U.S. Congress, Office of Technology Assessment (1981) reported that on some particularly fragile lands there are no currently available ways to sustain high levels of production. On other lands, technologies to enhance productivity are often not applied because users are not convinced the new technology will be profitable, innovative technologies require more management, and capital investment is greater than users can afford (U.S. Congress, Office of Technology Assessment 1981). The use of rangelands can be enhanced, however, with multiple species grazing (Baker and Jones 1985). These technological enhancements require the broadening of forage management and wildlife management into vegetation management.

Table 32.—Range forage prices (dollars per head per month) as determined by grazing fees on National Forest System lands and by market value appraisals.

National Forest System Region[1]	Grazing fee[2]	Market clearing price[3]
1	1.35	5.64
2	1.35	6.34
3	1.35	4.73
4	1.35	4.12
5	1.35	4.53
6	1.35	4.36
8	0.65	3.33
9	2.53	3.33

[1]*Assessment regions correspond to the following National Forest System regions: Northern Rocky Mountains, 1, 2, 4; Southwest, 3; California, 5; Pacific North, 6; Northern, 9; Southern, 8.*

[2]*See USDA Forest Service, and USDI Bureau of Land Management (1986), for grazing fee formula. Regions 8 and 9 prices were derived from equivalent hay price. Prices are based on dollars per head per month as used in grazing fee bills for collection.*

[3]*Market Value Appraisal, 1983, USDA Forest Service, updated to 1987. Regions 8-9 prices derived from hay prices.*

Source: Frandsen (1988).

DETERMINANTS OF VALUE

Range Forage For Livestock Production

The value of range forage grazed by livestock is derived from the value of the livestock produced. Thus, the value of range forage is a function of the values of the livestock, the value of other types of feeds and forage that might be used, and the efficiency of the livestock operation (Bartlett 1986). On NFS lands and BLM-administered lands, range forage is allocated by public policy. Thus, the value of range forage is not determined within a market system. In the past, the determinants of value within the fee system have included beef cattle prices, prices paid index, and the private grazing land lease rates (USDA Forest Service and USDI Bureau of Land Management 1986). A comparison of the 1987 public grazing fees and estimates of the market clearing price of forage by regions are shown in table 32.

An important consideration for resource decision-making is the current value of range grazing for livestock and any changes in that value in the future. The value of range forage over time should reflect changes in the factors that affect the use of range forage. These factors include outputs produced from forage, i.e., beef cattle or sheep, and changes in the production of other types of feeds that could be used as substitutes. Thus, trends in the value of private range forage might reflect historical trends in the available market transactions for forage, such as private grazingland lease rates. The valuation of private grazingland lease rates includes a multiplicity of factors, among which are services and facilities provided with the lease. As any historical shifts in these additional factors are difficult to examine, caution must be exercised in evaluating the trends in market prices associated with private land lease rates. In addition, the value of deeded private range may include values not measured in the private grazing land lease rates, such as the option to use the deeded land with greater flexibility than leased grazing land.

As the projection period for the assessment is 50 years, two historical series will be examined to assess trends in range forage values: the recent historical trend (1968-86) and the long-term historical trend (1870-1970). The trends in the recent historical past are most likely to influence the next 10 years whereas the longer historical series are most likely to influence the future long-term trend. The price in constant dollars (net of inflation) will be used to determine trends in the value of the range resource for livestock grazing.

The recent historical trends in the determinants associated with livestock grazing are given in table 33. The high inflation rates of the 1970s are seen in the difference between the nominal prices and the real (constant) prices. Although all nominal values increase over 1968-85, constant dollars remain nearly steady or decline for beef cattle, private grazing land lease rates, and wool prices. The cyclical nature of livestock production is also apparent in the cyclical pattern of the beef cattle prices.

The recent historical trends in the private grazing land lease rates (constant dollars) indicate a slight decline of 1% annually during 1966-86 (fig. 55). Private grazing land lease rates include various services other than the use of the range forage. This trend also reflects any changes in services other than forage provided, as well as a potential change in the value of the private grazing land lease rate.

Trends in hay prices (constant dollars) during 1968-85 have moved upward about 0.7% annually (fig. 56). Greater volatility is seen in this series when compared with the private grazing land lease rates (fig. 55).

Table 33.—Hay prices (dollars/ton), livestock prices (dollars/CWT), private grazing land lease rates (PGLLR) (dollars), and wool prices (cents/lb) from 1968 to 1986.

	Hay		Beef cattle		PGLLR		Wool[1]	
Year	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real
1968	23.60	23.60	22.04	22.04	3.65	3.65	40.5	40.5
1969	24.70	23.40	27.00	25.57	3.82	3.62	41.8	39.6
1970	26.10	23.42	29.50	26.48	4.05	3.64	35.4	31.8
1971	28.10	23.86	29.50	25.05	4.06	3.41	19.6	16.6
1972	31.30	25.38	36.80	29.84	4.17	3.38	35.0	28.4
1973	41.60	31.68	43.00	32.75	4.57	3.48	82.7	63.0
1974	50.90	35.54	39.20	27.37	5.82	4.00	59.2	41.3
1975	52.10	33.12	35.20	22.38	5.75	3.66	44.8	28.5
1976	60.20	38.97	36.10	21.57	6.37	3.81	66.0	39.4
1977	53.70	30.08	36.00	20.17	7.06	3.95	72.0	40.3
1978	49.80	26.00	47.60	24.85	7.11	3.71	74.5	38.9
1979	59.60	28.59	64.90	31.13	7.53	3.51	86.3	41.4
1980	70.90	31.19	64.20	28.24	7.88	3.47	88.1	38.8
1981	67.30	26.99	59.10	23.70	8.83	3.54	94.4	37.9
1982	69.30	26.13	57.70	21.75	8.36	3.15	68.6	25.9
1983	75.80	27.50	56.40	20.45	8.85	3.21	61.2	22.2
1984	72.70	25.45	57.79	20.19	8.86	3.10	79.5	27.8
1985	69.10[2]	23.43[2]	53.70	18.16	8.40	2.84	63.3[2]	21.5[2]
1986	NA	NA	51.79	17.05	8.50	2.80	NA	NA

[1]*Prices do not include wool support price payments.*
[2]*Preliminary.*
Note: Real prices are reported in constant (1968) dollars and are net of inflation or deflation.
Source: Hay and wool, U.S. Department of Agriculture (1968-1985); beef cattle prices, PGLLR, USDA Forest Service, and USDI Bureau of Land Management (1986).

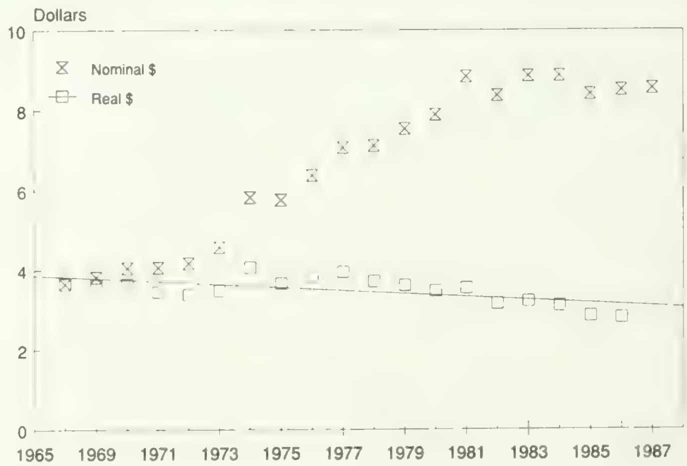
An examination of the determinants over a longer historical period indicates positive increases in all values, although fluctuation in prices associated with wool has been considerable (figs. 57 and 58). The annual increases in beef cattle prices and in sheep and lamb prices (constant dollars) over this 100 year period is nearly 1% (Manthy 1978). Wool, hay, and corn prices (constant dollars) show a greater fluctuation over this period but no clear trend is seen.

Range Vegetation

The determinants discussed above relate to the value of range forage in livestock production. The value of range vegetation is reflected in, but is not often measured by the value of grazing for wildlife, wild horses and burros, the habitat for threatened and endangered species, and the recreational experiences. The future value of range vegetation based on other output indicators might be different from the trends determined from forage for livestock. Increases associated with access hunting fees may reflect an attempt by the producer to find the market equilibrium price, but over the short-term indicate a substantial increase in value (fig. 51). Although not expressed in terms of monetary value, the increased number of threatened and endangered plant species suggest an increase in the value of rangelands as habitat for these species. As discussed earlier in this chapter, increased competition for the mix of resource outputs imply a continued and increasing social value for range vegetation management.

SUMMARY

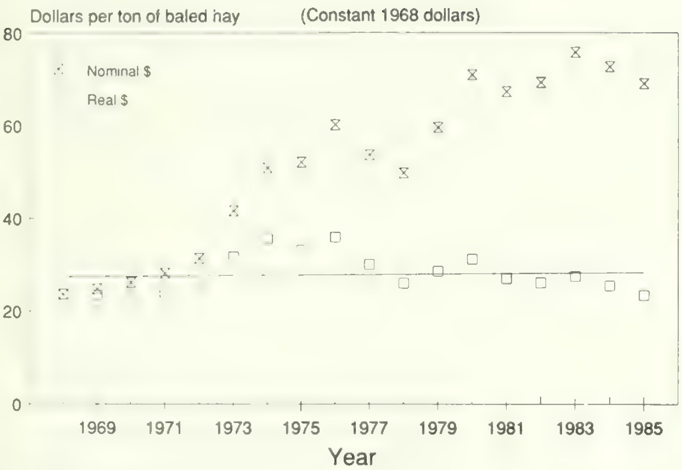
The desirability of the projected future depends on society's social, economic, and environmental values concerning the range resource. Society's ideas about the range resource regulate preferences that function to influence the use of rangeland. Livestock enterprises and livestock grazing on rangeland will continue to contribute to the social well-being of rural communities. The increased demand for recreational experiences will



NOTE.--Real rates are reported in constant 1968 dollars.

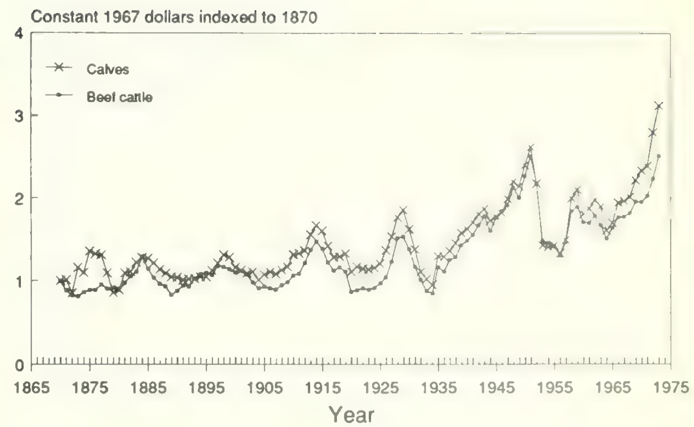
Source: USDI, Forest Service and USDI, Bureau of Land Management (1986)

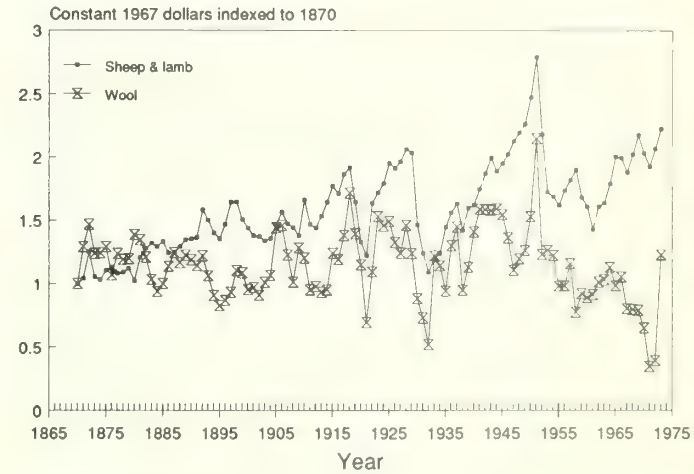
Figure 55.—Private grazing land lease rate.



Source: USDA (various years)

Figure 56.—Hay price per ton received by farmers, 1968-1985.





Source: Manthy (1978)

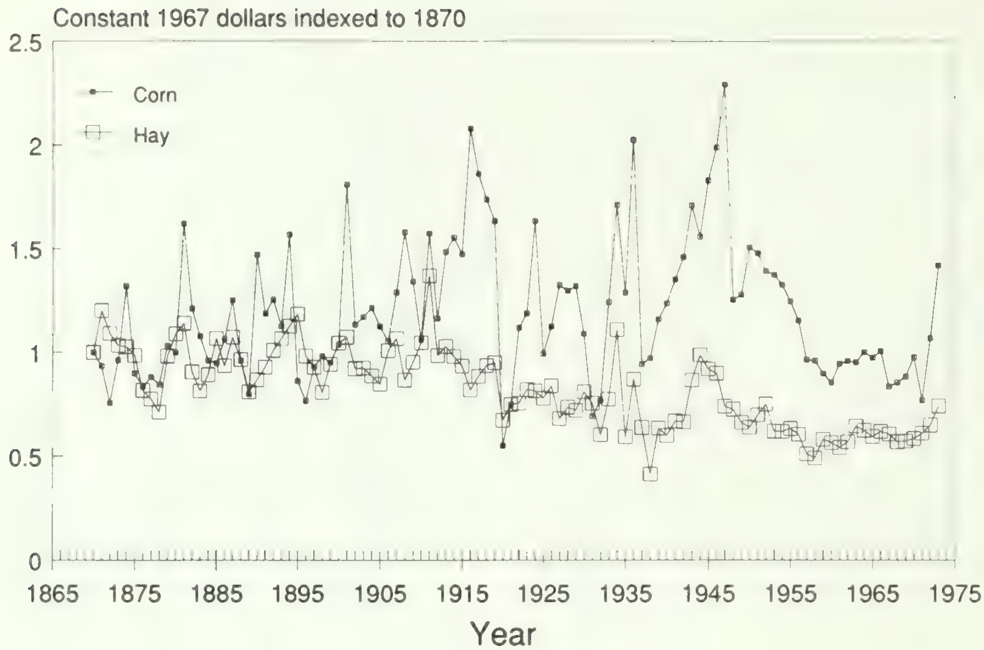
Figure 57.—A 100-year historical trend of prices received: livestock and wool.

increase the interaction between ranching operations and urban dwellers. Concern for rangeland health will be heightened in the future as demands for wildlife habitat, wild horse and burro habitat, and habitat for threatened and endangered plants and animals are increasing along with livestock production on forest and rangelands.

Although the projected supply of forage appears adequate to meet the projected demand for livestock grazing, the distribution of grazed forages will likely vary from historical patterns. In light of the overall increase in forage demand, a decline in relative shares of public grazing and irrigated pasture suggests that livestock operations unable to buy, grow, or otherwise obtain forage for all seasons to replace public forage or irrigated pasture will not be part of the future growth in this industry. Thus, fewer livestock operations will be associated with public lands, with a potential decline in service industries associated with livestock production in these rural communities. This decline, however, is tied to social pressure to remove livestock from public lands, which is related to an increased demand for recreation and wildlife outputs. Services associated with recreation will likely increase in these rural communities.

The enhanced rangeland productivity is projected to meet only the increased forage demand for livestock. Although domestic and wild grazers and browsers are often complementary users of rangeland and, thus, competition is not 100% temporally and spatially, grazing pressure from wildlife and livestock will increase in the future.

Recent historical trends in the values of private grazing land lease rates, prices for beef cattle and wool indicate a flat or declining trend. Trends over the period corresponding to the projection period of the assessment (50 years) indicate an increase of 1% in the prices of beef cattle, sheep and lamb. Wool, hay, and corn prices show a greater fluctuation over this period with no clear trend.



Source: Manthy (1978)

Figure 58.—A 100-year historical trend of prices received for corn and hay - indexed to 1870.

CHAPTER 6: ISSUES AND OPPORTUNITIES TO MANAGING THE RANGE RESOURCE

INTRODUCTION

The projections discussed in Chapters 4 and 5 identified future shifts in the forage production. Forage production on public lands and from irrigated pasture was projected to increase only slightly whereas the total demand for livestock forage was expected to rise. The relative declines in these sources of forage suggest that the management of alternative sources of forage, such as private lands, will intensify. Not only will this intensification involve livestock grazing, but also the need to diversify ranch/farm operations to stabilize income over the long term. Increasing demands for wildlife, recreation, and water production are also suggested (Flather and Hoekstra in press, Guldin in press). A future in which resource use intensifies, but management does not, poses the possibility that our Nation's ecosystems will not likely improve in condition or productivity. The management issues associated with the range resource are now broader than domestic livestock grazing. One important aspect of this national assessment is to review issues and opportunities that exist to potentially reduce these impacts and costs.

Management issues and opportunities are grouped into four categories: the *management of range vegetation; management of grazers and browsers*, both wild and domestic; *social issues*; and *planning*. Reports from National Forest System (NFS) range, wildlife, and fish managers, Bureau of Land Management (BLM) wildlife and fish managers, and state wildlife and fish managers were reviewed for perceptions of current management issues, opportunities that exist to address these issues, and obstacles to resolving these issues. In addition, published reports by special interest groups, professional organizations, producer groups, and universities were reviewed.

RANGE VEGETATION MANAGEMENT

Vegetation management issues revolved around providing the type of vegetation on public and private lands necessary for the production of a mix of resource outputs including forage for domestic and wild herbivores, water quality and quantity, air quality, open space, endangered plants and animals, genetic material, recreational use, plant diversity, community stability, scenic quality, and minerals (Cordell in press, Flather and Hoekstra in press, Guldin in press, USDA Forest Service 1988b, USDA Forest Service RPA Staff in press). Management issues of particular concern included the seasonal and spatial availability of forages for both wild and domestic herbivores, healthy riparian vegetation, and the control of undesirable plants.

Availability of Forage for Wild and Domestic Herbivores

Issues

An adequate supply of year-round forage for wild and domestic herbivores, the exceeded life-time of existing range improvement practices, natural successional changes reducing habitat or forage availability, and human activities reducing habitat and forage availability were seen as limiting factors in the management of wild and domestic herbivores (Flather and Hoekstra in press, USDA Forest Service 1988b, USDA Soil Conservation Service 1987c, U.S. General Accounting Office 1988). The projected declines in the regional availability of public forage and irrigated pastures (Chapter 4) will intensify the increasing demands for alternative sources of forage.

Plant production is greatest during periods of adequate moisture and optimal temperature. Outside of their optimal growth periods, grasses, forbs, and shrubs may grow little, if at all. During these periods, accessibility to alternative sources of forage is critical for wild and domestic grazers. Poor vegetative conditions in crucial winter range is a management issue for big game (Flather and Hoekstra in press). Inadequate forage production in cool-season pastures during the summer months is a concern in the Northern region (USDA Forest Service 1988b, USDA Soil Conservation Service 1987b). Summer range for pronghorn in the Rocky Mountain region is poor because of a lack of forbs that remain green during July and August (Flather and Hoekstra in press). Alternative nutritional sources of forage during the winter in the Southern region are needed for domestic grazers.

The expired lifetime utility of many range improvement practices and the need to broaden the types of practices implemented were concerns for most range managers (USDA Forest Service 1988b). Range plant control treatments are designed to temporarily shift plant succession (Young 1983). Many of these improvement practices were implemented several years ago and succession has resulted in the need to again treat these sites to maintain the present grazing strategy. On public lands, the lack of range funds and declining budgets have restricted the implementation of improvement practices (fig. 52). In 1985, the Forest Service had 561 range conservationists and technicians overseeing 9,000 grazing allotments within 103 million acres. Thus on average, each person oversees 16 grazing allotments covering 184,000 acres (U.S. General Accounting Office 1988). Declining range improvement funds has restricted improvement practices on BLM-administered lands also. A current vegetation analysis is needed before

developing range management objectives for NFS lands. Range managers were concerned that lack of funds and personnel would restrict the development of ecological guidelines for conducting these vegetation analyses (USDA Forest Service 1988b). On private lands, the economic incentive to implement range improvement practices has weakened (Chapter 3). This economically-driven delay in range improvement on public and private lands is intensified because the original practices such as chemical spraying or fire are no longer acceptable, and suitable economic alternatives may not exist.

The need to broaden the types of practices implemented on pasture/rangeland is the result of traditional attitudes limiting improvement practices, in addition to environmental restrictions on previously used treatments, such as herbicides. Traditional attitudes concerning range management limit the approaches that can be taken on forest and rangelands. The spacing of tree plantings at similar densities in southern timber plantations can inhibit forage production (evenly spaced) or enhance forage production (unevenly spaced across the field). Often, fertilization and liming were the only management practices considered in the Northern region (USDA Forest Service 1988b). The benefits of converting to cool-season grasses and of delaying livestock grazing were often not obvious to land managers. In a survey by the National Association of Conservation Districts, ranchers and farmers believed that the education of land operators was essential to achieve the application of proven range management practices (National Association of Conservation Districts 1979).

Succession affects continual changes in the vegetation structure on forest and rangelands (fig. 22). Abandonment of cropland and pastures, particularly in eastern United States, has resulted in declining acreages of open nonforested habitat, as the plant community moves toward the potential natural community. This displaces some wildlife species, represents a forage loss for wild and domestic herbivores, and also results in a loss of scenic vistas (Flather and Hoekstra in press). In some ecosystems, past use has been so intensive as to shift the ecosystem response to management (Chapter 2). Conversion to return the original vegetation type is an expensive process.

The USDA Soil Conservation Service (1987c) reported that nationally nearly 117 million acres of rangeland require intensive treatment such as brush management, range seeding, or erosion control. Brush treatment was recommended for sites where these invading woody plants were not part of the climax plant community or where these plants have expanded to densities much greater than the natural community. Not only does the encroachment of shrubs reduce forage, but water runoff may be higher, accelerating soil erosion (USDA Soil Conservation Service 1987c).

Opportunities

Management opportunities for range vegetation management exist in previously developed but not yet implemented technology, and in developing technology. The seasonal availability of forage can be improved by interseeding of a mixture of species within a pasture, converting part of the grazingland to other forage species, or adjusting the mix of animal species. Seeding warm-season grasses in cool-season pastures extends the period of available forage in the Northern region and in the plains area of the Northern Rocky Mountain region. On-going research at federal and state agricultural experiment stations is accelerating the interest in and use of warm-season grasses (USDA Soil Conservation Service 1987b). Techniques have been developed to process native grass seeds so that conventional grass drills can be used, and the availability of drills capable of seeding native seed is also increasing (USDA Soil Conservation Service 1987b).

Subterranean clover is a cool-season forage legume that may potentially improve winter nutrition for herbivores, and indirectly small game, on forested rangelands in the South (Johnson et al. 1986, Ribbeck et al. 1987). This species would grow most during the winter when other forage is of poor nutritional quality. This clover is also a major spring forage on the western coast of the Pacific Coast region. The only disadvantage is that it requires intensive grazing and management to be productive. Opportunities to interseed arid rangelands with adapted forbs were seen as possible methods to extend summer range use for pronghorns. On big game winter range, a reduction of domestic grazing could provide additional forage.

Within a mosaic of land ownerships, changing land uses place increasing importance on the vegetation management on lands available for grazing. Development around public lands such as ski developments or second homes, or the encroachment of urban lands into the rural areas creates barriers to migratory wildlife routes and limits access for livestock grazing. Coordinated management opportunities exist to mitigate problems associated with changing land uses or intermixes of land uses. Opportunities to exchange lands to block up crucial winter ranges in public ownership were seen as possibilities to address the seasonal shortage of forage for big game. Opportunities to mitigate the habitat loss of wildlife species also includes the outright purchase of lands by federal, state, or private groups (Flather and Hoekstra in press).

Research Needs

The lack of ecological knowledge in vegetation management and the need for technology transfer from researchers to managers were seen as issues in vegetation management research. A comprehensive understanding of the regulatory mechanisms of plant growth and how it responds to environmental extremes are objectives for further research (Society for Range Management 1989). Existing models used in resource management to forecast future plant communities and resource outputs have not been tested in different ecosystems or under different successional stages, and

the underlying ecological assumptions in these models need further examination (Sweeney and Wolters 1986). Additional study is needed to determine the impact of grazing systems on vegetation productivity (USDA Soil Conservation Service 1987b). Sustainable management systems to integrate land uses are needed to manage vegetation and other components of the ecosystem (see Planning section of this chapter).

Healthy Riparian Vegetation

Issues

Many western public resource managers believe that conflict arising over the management of riparian zones is, except for timber management, the most potentially explosive issue of today (Prouty 1987). The 1986 Audubon Wildlife Report identified damage to riparian zones by cattle grazing on public lands as the most serious current conflict between wildlife and livestock (Barton and Fosburgh 1986). Over 90,000 miles of streams and rivers providing nearly 3 million acres of riparian habitat are administered by the NFS and BLM (Prouty 1987). Riparian areas are attractive to recreationists for many reasons including presence of water, easy access, fishing opportunities, and esthetically appealing landscape (Johnson and Carothers 1982, Melton et al. 1984, Skovlin 1984). The stability and integrity of streambanks, and adequate shade and overhanging cover are important in maintaining healthy fish populations (Cummins 1974, Moring et al. 1985).

Riparian zones contain higher density and diversity of plant and animal species than adjacent uplands (Odum 1979). Livestock and wildlife use riparian areas disproportionately more often than upland habitats (Kauffman and Krueger 1984, Marlow and Pogacnik 1986). In Oregon, a riparian zone comprising less than 2% of the total land area produced 21% of the available forage and accounted for 81% of the total herbaceous vegetation removed by livestock (Roath and Krueger 1982). Of the 166 bird species nesting in southwestern United States, 127 (77%) were dependent on water-related habitat (Johnson et al. 1977). Forty percent of the vertebrate wildlife species in Colorado are associated with riparian areas that occupy 3% of the land area (Melton et al. 1984). Riparian zones also serve as migration corridors for wildlife, especially big game traveling between summer and winter ranges (Melton et al. 1984, Thomas et al. 1979). With all of these demands, riparian ecosystems are the most critical area for multiple-use planning (Platts 1979).

Opportunities

Proper vegetation management of riparian zones can produce a variety of resource outputs, including fisheries, wildlife, recreation, livestock, and water quantity and quality. Wildlife that utilize riparian areas include big game such as deer and elk, small game, nongame, and furbearers. Riparian area management presents the biggest challenge and opportunity for multiresource planning and cooperation. Western rangeland streams are in their present condition because 100 years of small, annual degrading effects were cumulative over time. Land managers must administer grazing strategies with finesse to meet today's needs while attempting to correct the mistakes of the past (Platts and Raleigh 1984).

Based on early research on riparian zones, many allotments on NFS lands receive less overall livestock use and have been changed from season-long grazing to other grazing systems. Rest-rotation grazing has been effective in rehabilitating riparian areas that are non-woody or have established woody stands (Platts and Nelson 1985a). In critical fish habitat, grazing has been eliminated by fencing some stream sections to protect spawning habitat of anadromous fish. The special management pasture offers an expensive, but flexible management practice to continue grazing under more focused management (Platts and Nelson 1985b). Different livestock species graze riparian areas in different ways. Sheep, which graze riparian areas without extensive damage, are no longer present on many allotments (Platts and Raleigh 1984).

Fishery biologists are attempting to improve degraded stream sections through instream structures designed to catch sediment and through planting willows and other shrubs to stabilize streambanks (Malespin 1985, McCluskey et al. 1983, Storch 1979). Channel structures that deposit sediment enhance riparian development by providing more favorable moisture and nutrient regimes and a reduction in flow velocity (DeBano and Heede 1987). Willow planting provides habitat for many wildlife species in a short amount of time at a low cost (McCluskey et al. 1983).

Research Needs

Much has been learned in the past 20 years about the structure and function of riparian zones, but this complex ecosystem is still not fully understood. Recent and present research is concentrating on entire riparian ecosystems and watersheds (Platts 1986). Grazing strategies are being matched to the physical conditions of the grazing area (Platts and Raleigh 1984). Researchers are focusing on how riparian areas function, and studies are underway on how to get degraded streams to function properly again. The BLM in Oregon is learning how to manage mud or sediment by examining the basic stream processes and maintaining vegetative cover during peak runoff (Elmore 1988, McKinney 1988). Nutrient cycling within and through riparian areas is being studied (Warwick and Hill 1988). Changes in the microbial aspects of riparian zones may provide an early warning to unwanted successional change (Hussey et al. 1985). Scientists are also looking at the impacts of natural disturbances such as flood events and how the stream changes with these disturbances (Platts et al. 1985). Inventory techniques are being modified and refined to better judge the condition of riparian areas (Platts et al.

1987). Platts (1986) stated that research leading to successful rehabilitation of riparian areas is in its infancy and should receive the highest priority in the future.

Little information is available on the riparian habitat requirements of threatened and endangered species or invertebrates (Patton 1977, Skovlin 1984). Few studies identify how present cattle grazing strategies will restore riparian habitats (Platts and Raleigh 1984). Range managers need more information on the costs and benefits associated with different livestock management strategies. The impacts of multispecies grazing in riparian areas needs to be explored both biologically and economically. Long-term hydrologic impacts of livestock grazing need to be addressed (Blackburn 1984).

Knowledge gaps exist between fishery and wildlife biologists, and range managers (Skovlin 1984). Range, wildlife, and fishery scientists base management decisions on functional sets of criteria, such as meat production, wildlife population size, or quantity and kinds of fish (Platts and Raleigh 1984). Platts and Raleigh (1984) did not find a single published interdisciplinary grazing study in their literature review. They stated that a compelling need exists for studies that identify common goals and incorporate the concerns of all users, including ranchers, fishermen, hunters, ecologists, and recreationists.

Undesirable Plants

Issues

The spread of undesirable plants is a particular concern among resource managers (Flather and Hoekstra in press, USDA Forest Service 1988b). An undesirable plant is one that is unacceptable in light of planned land use or that is unwholesome to rangelands or range animals (Vallentine 1980).[19] These plants can be exotics that spread into the native community or native species whose dominance is undesirable. Acceptance of a plant species depends on what plant species, and how, when, where, and for what is it desirable (Vallentine 1980). Plants undesirable for one grazing animal may be valuable for other herbivores, as habitat for wildlife, or valuable to other industries such as beekeeping. For example, tall larkspur is poisonous to cattle, but is palatable, nutritious forage for deer and sheep (Vallentine 1980). The introduction and persistence of nonnative plants and animals is jeopardizing the habitat of native plants and animals including some threatened and endangered species (Chapter 2).

Species and rates of infestation differ across the United States. Diffuse and spotted knapweeds reduce forage production, decrease range carrying capacity, have high fibre content, and form solid stands with their competitive advantage of allelopathy (Maddox 1982). These two species have infested over 3.5 million acres in Oregon, Washington, Idaho, and Montana. Maddox (1979) estimated that the economic loss to cattle operations in 750,000 acres of knapweed-infested range is $600,000 annually. Grazing capacity on elk-bighorn-deer winter range has been reduced 35% to 80% from knapweed invasion in western Montana (Mass 1985). Leafy spurge can lower range carrying capacity by 50% to 75% (Maddox 1979). This loss is the result of decreased forage production from leafy spurge competition, and decreased forage availability because cattle will not graze areas heavily infested with spurge (Lym and Kirby 1987). The current infestation level is estimated at 2.5 million acres in North America (Lacey et al. 1985). Annually, $6 million is spent for spurge control and over $7 million in forage and beef production is lost from decreased forage production on spurge-infested rangelands in North Dakota (Lacey et al. 1985). Infestations of yellow starthistle have been reported in 23 of the 48 conterminous states; over 7.4 million acres are infested in California alone (Maddox et al. 1985). Although this plant has a negative impact on grazingland, grain and seed crops, and is toxic to horses, yellow starthistle is a valuable honey plant for the maintenance of bee colonies in California (Maddox et al. 1985).

Introduction and spread of exotic species has been facilitated by impurity in crop seed, adhesion to animals, soil surrounding roots of nursery stock, and the deliberate introductions of plants as forage, fiber, medicinal, ornamental, erosion control, and timber stock (Baker 1986). The spread of native species can be associated with natural succession, climatic fluctuations favoring these species, and local denudation such as road right-of-ways, stock trails, off-road vehicle use, or heavy grazing by livestock. Within a geographic area, native and exotic plants can spread along transportation corridors (railroads, highways, stock or recreation trails), and can spread by cultural practices such as cropping. The activity that most ensures a successful plant invasion is disturbance caused by human activities (Baker 1986, Mass 1985). Because the spread of undesirable species is oblivious of ownership, the problem is a multi-agency one. Lack of funding, research, technology transfer, awareness, and integrated control programs are allowing a significant increase in undesirable plant species.

The reliance of past management on chemical control has resulted in a related management concern, the loss of pesticides. Environmental legislation has increasingly focused on the dispersal of toxic substances in the environment (table 34). Previously used chemicals are being withdrawn from public and private use because of environmental concerns. This restriction places a greater importance on the development and implementation of environmentally safe control methods.

The implementation of any control method requires the consideration of costs and benefits. Fire has been the least expensive method for controlling undesirable vegetation (Stoddart et al. 1975). Poor economic conditions within the ranch/farm sector have resulted in a sharp drop in pesticide production in recent years. Surveys in North Dakota indicate that about 50% of the total combined acreage including cropland, alfalfa, hay, rangeland, and summer fallow was not treated with any pesticide in 1984 (Agrichemical Age 1986).

[19] *Federal and state laws define certain plants as noxious weeds because they are especially undesirable, troublesome, and difficult to control.*

Table 34.—Pollution control statutes in the United States.

Year passed	Statute
1970	Resource Recovery Act (amendments to the Solid Waste Disposal Act)
1972	Water Pollution Control Act Amendments
1972	Federal Environmental Pesticide Control Act (Amendments to the Federal Insecticide, Fungicide and Rodenticide Act)
1974	Safe Drinking Water Act (Amendments to the Public Health Service Act)
1976	Resource Conservation and Recovery Act (Amendments to the Resource Recovery Act focusing on hazardous wastes)
1976	Toxic Substances Control Act
1977	Clean Water Act (Amendments to the Water Pollution Control Act)
1978	Federal Insecticide, Fungicide and Rodenticide Act Amendments
1980	Comprehensive Environmental Response, Compensation, and Liability Act (commonly referred to as the Superfund)

Opportunities

The intensified public awareness of herbicide use on rangeland, coupled with increasingly sophisticated application techniques and increased knowledge of herbicide chemistry, has provided the incentive for research on the fate of herbicides in the ecosystem and for alternative control methods such as biological control. Present research on chemical control of undesirable plants has focused on short-lived chemicals that are highly toxic when first applied, are used in smaller quantities per unit area, and break down rapidly (Conservation Foundation 1984).

Increased interest in biological control agents is the result of several factors including the marginal economics of rangeland, the increased cost of petroleum-derived chemicals, the development of resistance in some weeds to herbicides, the inaccessibility of rangeland to herbicide application, and the restrictions on herbicide use along waterways and on public land (Nowierski 1984). Worldwide, 57 attempts to partially or completely control plants biologically have been successful and one of the startling successes was the control of St. Johnswort in California (Dahlsten 1986). Agents examined for use in biological control include insects, pathogens, and grazing animals (table 35). Biological control agents offer a number of management opportunities for rangelands: (1) the application on economically marginal land where expense or difficult terrain excludes the use of herbicides or cultural management, (2) permanency where the established control agents reappear annually to impact the undesired plant, (3) environmental safety with no toxic residues, (4) specificity where only the undesired species is attacked, (5) cost-effectiveness, and (6) the potential integration of biological control with chemical and cultural management strategies (Nowierski 1984). Unlike chemical or mechanical efforts that attack the plant for short-term success, biological control methods take longer to get established, the populations must build up, and the kill extends over a longer period of time as the host and control agent equilibrate. Presently many biological agents are under study, but only a few have been successfully released. Animals, such as sheep and goats, will graze plants such as leafy spurge (Fay and McElligott 1987, Landgraf et al. 1984) and can be an economically efficient method for control (Lacey et al. 1984). Proper management is needed to avoid any toxicity response to leafy spurge by sheep.

Opportunities exist to increase the public and private manager's awareness of undesirable plants through a coordinated state effort. Multiresource funding on public lands would give the range manager the funding and support to inventory, control, and monitor undesirable plants. Increasing the awareness of undesirable plants becomes important as interest in xeriscaping (landscaping with drought-hardy plants) offers another method for plant dispersal across the western United States.

Research Needs

The ecology of undesirable plant species is little known. The physiology and ecology of undesirable plants is an important step in developing environmentally sound control methods (Society for Range Management 1989). The mathematical modeling of invasion by colonizing plants has not been extensively developed but offers much promise in understanding the biology of these species (Bazzaz 1986). The ease of establishment and spread of knapweeds, the role of range condition in determining invasion rates of leafy spurge, and the unknown role of livestock grazing in the control of several undesirable plants were knowledge gaps identified for the western United States (Leininger 1988).

Although methods of chemical control may be available for a variety of undesirable plants, biological treatment is more likely only under study at present (table 35). Biological control appears to offer numerous advantages to control pests on rangelands, but several disadvantages exist. Biological agents are necessarily subjected to an exhaustive series of tests to guarantee their safety. Although geographically separate, leafy spurge, Canada thistle, and Tansy ragwort have plant relatives that are threatened or endangered plant species (table 35, Appendix C). Biological control methods must be

Table 35.—Some plant species of special concern on pasture and rangelands and their control treatments.

Species	Common Name	Treatment		Biological treatment			
		Chemical[1]	Mechanical	Insects	Pathogens	Grazing[2]	Plants[3]
Introduced							
Bromus tectorum	Cheatgrass	Yes	Yes			C	
Cardaria draba	Hoary Cress	Yes		Study[4]	Study		
Carduus acanthoides	Plumeless thistle	Yes		Study	Study		
C. nutans	Musk thistle	Yes	Yes	Study	Study		Yes
C. pycnocephalus	Italian thistle				Study		
C. tenuiflorus	Slenderflower thistle				Study		
Centaurea calcitrapa	Purple starthistle	Yes					
C. diffusa	Diffuse knapweed	Yes	Yes	Study	Study	S	
C. maculosa	Spotted knapweed	Yes	Yes	Study	Study	S,C	
C. repens	Russian knapweed	Yes	No	Study	Study	S	
C. solstitialis	Yellow starthistle	Yes		Study			
Conium maculatum	Poison hemlock	Yes					
Cytisus scoparius	Scotch broom			Study			
C. monspessulanus	French broom			Study			
Halogeton glomeratus	Halogeton	Yes		Study		S,G	
Hypericum perforatum	St. Johnswort	Yes	Yes	Yes		S	
Isatis tinctoria	Dyers woad	Yes		Study			
Lepidium latifolium	Perenial peppergrass	Yes	Yes				
Linaria dalmatica	Dalmation toadflax	Yes		Study			
Salsola paulsenii	Barbwire Russian thistle						
S. iberica	Russian thistle			Study			
Senecio jacobaea	Tansy ragwort	Yes		Yes			
Sonchus arvensis	Perennial sowthistle						
Tamarix pentandra	Saltcedar	Yes	Study				
Ulex europaeus	Gorse			Study			
Euphorbia esula	Leafy spurge	Yes	Yes	Study	Study	G, S	Yes
Cirsium arvense	Canada thistle	Yes		Study	Study	Study	Yes
Native							
Delphinium spp.	Tall larkspur	Yes				D, S	
Gutierrezia sarothrae	Snakeweed	Yes		Study	Study		
Larrea tridentata	Creosotebush	Yes	Yes	Study			
Opuntia spp.	Prickly pear cactus	Yes	Yes	Yes			
Prosopis juliflora	Mesquite	Yes	Yes	Study	Study	C,G after burn	

[1]*Chemical treatment with yes indicates that there are chemicals on the market that have been used to treat this species. Species may require one or more chemical, mechanical, or biological treatments.*
[2]*G = Goats, S = Sheep, D = Deer, C = Cattle.*
[3]*Other plants can out compete this species.*
[4]*Research under way.*
Source: After Leininger (1988); U.S. Department of Agriculture, Agricultural Research Service (1984); USDA Forest Service, Intermountain Region (1986); Vallentine (1980).

specific enough to attack only one spurge in a genus with over 100 species. These conflicts of interest intensify the research required to develop a host-specific biological agent.

Current research efforts in the use of livestock for plant control appears to be small. Brock (1988) stressed that very little is known about the impact of short-term rotational-intensive grazing programs on less desirable forage. The combination of technology in weed, range, and animal sciences in a well-defined long-term research program is needed to assess the role of livestock grazing in integrated pest management programs for range (Brock 1988).

Early work on chemical control focused on the development of long-lasting compounds which would provide long-term protection and require fewer applications (Conservation Foundation 1984), however this research did not focus on the ultimate fate of herbicides in the environment (Scifres 1977). The most important research priority identified by members of the Weed Science Society of America was the need to develop new methods for controlling the movement of herbicides into ground water, surface water, and air (McWhorter and Barrentine 1988). Within this research area, specific research topics included the development of new application techniques that minimize or eliminate herbicides and their residues in air and water, and techniques that regulate the movement of herbicides through the soil profile to avoid contamination of groundwater.

MANAGEMENT OF GRAZERS AND BROWSERS

Management issues related to wild and domestic herbivores focused on the number and kind of animals, seasonal distribution of these animals, availability of

suitable grazers and browsers, and the management of large herbivores on public lands. Although the management of livestock on private and public lands has a long history, the management of wild browsers and grazers is a relatively recent phenomena (Flather and Hoekstra in press). Questions still remain as to the specific objectives of wildlife and fish management. Should wildlife and fish be maintained on islands of habitat or as part of the total landscape (Berryman 1983)? Managing wild grazers and browsers to be part of the landscape requires integrating the forage and browse needs of these animals within a multiple species grazing program on range and forest land.

Public land managers' concerns addressed the management of land, whereas state agencies were concerned with the conversion of forest or rangeland to uses not compatible with wildlife (Flather and Hoekstra in press, USDA Forest Service 1988b). The impact of herbivores on riparian vegetation, also a concern, was discussed in the vegetation management section above.

Multiple Species Grazing

Issues

Managing for the needs of livestock, wild herbivores, and other wildlife species were concerns raised by resource managers (Barton and Fosburgh 1986, Flather and Hoekstra in press, USDA Forest Service 1988b). Overgrazing by livestock, overutilization of riparian areas by herbivores, lack of suitable grazers, the lack of proper grazing systems, and the need to manage for both wild and domestic herbivores were among the concerns.

Within the Forest Service planning process, range managers were concerned that the development of allotment management plans (AMP) would be hindered by time/personnel/funding problems (USDA Forest Service 1988b). The development of the AMP is the site-specific planning process designed to meet the resource objectives in the Forest Plan. The standards and guidelines associated with the Forest Plan address the ecological management objectives for plant associations, utilization objectives, and riparian objectives. This need to develop or revise allotment management plans that meet the planning objectives on BLM lands was also raised as a management concern. Difficulties with permit administration and violations of the terms of the permit were also management issues on public lands.

The most important wildlife and fish management issue cited by BLM biologists was the effect of livestock grazing on wildlife habitat (Flather and Hoekstra in press). The deteriorated quality of big game winter range, small game habitats, and riparian communities, as well as threatened and endangered species were issues related to livestock grazing. Because the mandate to manage BLM-administered lands for multiple use is a recent direction, comprehensive information is lacking on the amount and status of wildlife and fish populations and their habitats, and the distribution of threatened and endangered species. This lack of information is inhibiting effective management on BLM-administered lands (Flather and Hoekstra in press).

The suitability and availability of grazers or browsers was another concern of resource managers. Certain lands, because of vegetation or terrain, are more suited to one type of grazer or browser, or to a mix of these animal types. The Rocky Mountain region has a large area of rangeland that is best suited for domestic sheep use, or because of vegetation management purposes, needs a change to browsing animal. This lack of suitable herbivores was also a problem for managing lands infested with certain undesirable plant species. Sheep and goats can graze range infested with woody species, but limited markets restrict the availability of these animals for grazing public lands and restrict an expansion of sheep enterprises within the private sector. Resource managers on BLM lands reported acres of suitable habitat for the desert bighorn, but no animals available to place in these areas.

About 136 million acres of nonfederal rangeland are well-managed, about 134 million acres could be improved by refinements in grazing management, and about 117 million acres need more intensive measures (USDA Soil Conservation Service 1987c). Controlling livestock numbers, and season and duration of grazing could improve the condition of 134 million acres of nonfederal rangeland. The desired vegetation is present on this rangeland, but plant vigor or stands could be improved by such practices as proper grazing use, deferred grazing, planned grazing systems, and fencing and water facilities for improved animal control and grazing distribution. The remaining 117 million acres would require more intensive treatment, such as brush management, range seeding, or erosion control (USDA Soil Conservation Service 1987c).

Economic pressures in the livestock industry have influenced the viability of many livestock enterprises. In 1986, 43% of the beef, hog, and sheep farm/ranch enterprises had negative net cash household incomes (Gee and Madsen 1988). Low livestock prices, high production costs, low land values, and little borrowing power may necessitate a diversification of multiple use within livestock enterprises (Grazing Lands Forum 1987). The Special Advisory Committee to the National Cattlemen's Association reported in 1982 that opportunities for profitable operations through 1990 will go largely to the better informed and more able planners and managers (National Cattlemen's Association 1982). This forecast will probably apply in the near future also.

Opportunities

Management opportunities to enhance the use of herbivores on forest and rangelands exist. For some situations, planning methods or organizational structure are present but limited by funding or personnel. The development of allotment management plans on public lands would facilitate the implementation of desired management objectives, but funding and personnel restrict the number of these plans that can be accomplished.

In other situations, the technology transfer to public and private management limits the optimal use of range and forest lands.

The management of multiple species of grazers and browsers could increase the efficient use of range and forest vegetation (Baker and Jones 1985). Multiple species grazing includes the grazing of one animal after another has already grazed the area, or the grazing of two of more species at the same time. Animal species could include domestic, wild, or animals of both types (Baker and Jones 1985, White 1987). The volatility in the cattle industry has sparked a recent interest in the profitability of wildlife within a ranching operation (Bedell and Rasker 1987, Rollins 1988).

As summarized by Baker and Jones (1985), the advantages of multispecies grazing systems for domestic animals include:

1. *Complimentarity*: Different animal species have different preferences for plant species, differential ability to digest various types of forage, and different patterns of forage harvesting (animal behavior).
2. *Improved pasturerange management and forage production*: Multispecies grazing enhances herbaceous production through increased species diversity and the maintenance of plants in vegetative states.
3. *Parasite management*: Alternating pastures between species helps to break the life cycles of parasites.
4. *Predator control*: Aggressive behavioral differences in grazing animals may help reduce predator losses.
5. *Diversification and income stability*: The risk associated with volatile market prices is spread over a number of outputs rather than a single product.

Multiple species grazing also carries some disadvantages: increased facility costs because of diverse species requirements, potential labor conflicts such as the coincidence of calving and lambing, need for increased management skills in the knowledge of species nutrition, diseases, parasites, breeding practices, marketing, and predator control (Baker and Jones 1985). Although the spread of disease is a concern in a multispecies grazing operation (Davis 1985), certain operations may reduce the likelihood of disease spreading from livestock to wild herbivores. For example, the only new animals annually introduced to a cow-calf operation are bulls which have been carefully chosen and inspected for disease, whereas in a stocker operation, many new animals, calves or yearlings, are bought and placed on the range each year (Cooperrider 1985).

Optimization in a multispecies operation results in an overall gain, rather than the maximization of a single species. Reduced numbers of each species in the operation might result in some loss in volume discounts on services and materials (Baker and Jones 1985). Multiple species management requires a careful evaluation of the range and forest land resource. Otherwise, this management may cause ecosystem deterioration when there is a critical habitat overlap of grazing animals, such as in riparian zones (Schuster 1985).

Research Needs

Resource managers and others associated with range recognize the need to broaden the research objectives for range. Range management must be based on ecological principles and defined in terms of species composition, ecological condition, and the ability to provide a specified sustained level of use. The need to understand the relations between plants, animals, and soil was one of seven research goals developed by the Society for Range Management. Research needs related to the grazing animal and better management systems included: (1) the impact of grazing animals on the morphology and physiology of pasture and range plants, (2) how plant characteristics such as palatability and nutrient value affect livestock behavior, distribution and performance, and (3) the response of grazing animals to micro- and macro-changes in plant communities (Society for Range Management 1989).

Information on the economics of range management, particularly different grazing systems, is a critical need (Society for Range Management 1989, USDA Soil Conservation Service 1987b). Management needs outlined by the Soil Conservation Service stressed the connection between ecological processes and the economics of management (USDA Soil Conservation Service 1987b). Landowner requests for SCS assistance to plan and implement grazing systems led to a recognition of limited information on the effects of grazing systems on soil compaction, infiltration, runoff, erosion, water yield and quality; on plant succession, seedling establishment, nutrient cycling, plant vigor, and plant populations; on appropriate stocking rates, animal performance, and livestock production; and on wildlife habitat response and populations (USDA Soil Conservation Service 1987b). Technology transfer needs of currently available research results were recognized by Society for Range Management (1989).

Livestock as a Vegetation Management Tool

Issues

Restrictions on the use of herbicides have resulted in steadily increasing populations of undesirable plant species. This problem occurs in timber plantations where plant control is desirable to reduce herbaceous and browse vegetation from competing with the planted trees. The problem with respect to herbivore grazing and habitat for threatened and endangered species on rangelands has been discussed in the section above on undesirable plants.

Opportunities

Different livestock species have different forage preferences and under proper management, these preferences can be used to modify the vegetation to meet resource objectives for timber, wildlife, or recreation. One of the

strategies recommended by the work group of the 1985 National Range Conference was to increase and enhance the opportunities to use livestock grazing to manipulate vegetation to meet land management objectives (Dunlop 1987). Livestock grazing has been used to reduce shrub growth which improves summer or winter range for wild or domestic grazers. The use of livestock as a vegetation management tool requires the presence of nutritional forage, consideration of the costs of control, and appropriate livestock for vegetation present. Proper grazing management should be timed to reduce the vigor of competing vegetation, maximize soil moisture and nutrients for desired species, and on tree plantations, to minimize browsing of tree seedlings and reduce trampling (Doescher et al. 1987, Sharrow and Leininger 1982). Sheep grazing reduces browse growth (Sharrow and Leininger 1982), and promotes herbaceous growth of grasses and forbs. On forested sites, this not only benefits the young trees but enhances the nutritional quality of the shrub regrowth for the benefit of the wildlife that return to the area once the sheep have been removed (Pearson 1983, Wray 1987).

Weyerhaeuser Company in southwest Oregon has implemented a grazing program on over 600,000 acres of forestland (Doescher et al. 1987). The Alsea District of the Siuslaw National Forest is testing the use of sheep in Douglas-fir plantations. Cattle grazing in southern pine plantations has also received much study (Pearson 1987). Because of the mixed vegetation and variable topography, ranchers on the Edwards Plateau in Texas have long recognized the value of grazing cattle, sheep, and goats on the same range. After mechanical brush treatment on the Grand Prairie in Texas, a grazing system of cattle was enhanced by Angora goats to consume the browse regrowth (Scifres 1980). Livestock grazing is being used in the Northern region of the United States to maintain openings for wildlife. In studies on the Fremont National Forest in Oregon and the Modoc National Forest in California, heavy early grazing by cattle reduced grass growth and enhanced shrub growth, indicating a potential tool to improve decadent bitterbrush on Great Basin deer winter ranges (Neal 1982). Grazing cattle and horses in Utah improved shrub habitat for wild herbivores also (Urness 1982).

Research Needs

Research needs for the use of livestock as vegetation management tools include better information on the type and kind of livestock capable of controlling different competing vegetation, such as browse under timber plantations and undesirable plants on rangelands (Society for Range Management 1989, USDA Forest Service 1988b). Range resource managers identified the need to define how a change in livestock type can manipulate the vegetation composition to improve other resource values, such as wildlife habitat (USDA Forest Service 1988b).

SOCIAL ENVIRONMENT

Issues

As the United States becomes increasingly urbanized, more people from urban areas will influence management in rural areas. Social issues raised by range managers included the public's perception about range and livestock and the current and future direction of the range profession.

Range resource managers stressed the importance of promoting, internally and externally, the perspective that range management is the science and art of managing range vegetation for multiple use outputs (USDA Forest Service 1987c). Unfortunately, many people perceive that range and range managers are only concerned with livestock. Busby (1987) criticized the Society for Range Management for narrowly directing its efforts only toward livestock use of rangelands. Resource managers stressed that livestock can serve as a management tool to modify vegetation on range and forest land as a replacement for chemical control, but this option is often not available because of public resistance to livestock grazing on public lands.

Animal rights and animal welfare issues were also concerns. Animal welfare concerns have fostered the development of newly formed animal care committees on many university campuses, the passage of the federal Dole/Brown Bill ("Improved Standards for Laboratory Animals Act"), revisions of the Public Health Service's animal care guidelines, and withdrawal of funding from institutions found in violation of animal care regulations (Schmidt 1987). Although these actions have focused on laboratory animals, animal welfare groups are also concerned about commercial meat and egg production (i.e., egg production using hens in battery cases, and veal production methods), and wildlife management (i.e., hunting and trapping).

Enrollment in natural resource programs has declined as a result of few entry-level jobs being available in the late 1970s. Undergraduate enrollment in wildlife programs in 1985 was 40% lower than the peak years of 1974-77 (Hodgdon 1987). Similarly, the 1985-86 enrollment in forestry technician programs was 40% of the 1977-78 enrollment (Martin and Jahnke 1987). Similar statistics for range programs were not available.

The issue of career advancement within the range profession concerned the upward mobility within an agency as well as the proper training for natural resource management work. Because career ladders do not exist for range conservationists within public agencies in some areas of the United States, it is difficult to find and keep competent people in range management.

Kennedy (1987), in examining career development of range conservationists in their first 3 years with the Forest Service, noted that working "out-of-doors" dominated the job motivations of these young professionals. University curriculums emphasize field methods, but, very few of the range conservationists surveyed spent over 50% of their time in the field; a significant proportion was spent in planning/administering and coordinating

between the Forest Service and their clients or other agencies (Kennedy 1987). Public involvement has become a significant part of natural resource management since the environmental legislation of the 1970s.

Opportunities

The need for increased communication between land managers and the public fostered a special session at the 1988 Annual Meeting of the Society for Range Management which dealt with the successful management of public rangelands (Hall and Hampton 1988). The need to communicate the broader concepts of range management within and without NFS was also identified in the National Range Workshop (USDA Forest Service 1987a). This need to enhance communication was also recommended by the 1985 National Range Conference which brought together ranchers, range professionals, agribusiness leaders, environmentalists, producer associations, and others interested in rangelands. Specifically, the group recommended that efforts be undertaken to inform the public with accurate and unbiased information about rangeland uses (Dunlop 1987). This recommendation stressed that the public needs to know and understand that the benefits achieved through proper livestock grazing practices include sustained resource values, such as soil productivity and water quality, wildlife habitat, threatened and endangered flora and fauna, ecological diversity, and forage production for domestic and wild herbivores (Dunlop 1987).

Research Needs

Increased urbanization in the United States will mean that a growing percentage of the population will have little or no direct contact with natural resource management. In California where urbanization is proceeding rapidly, public information and education programs for kindergarten through 12th grade are needed to demonstrate the relevance of California's natural resources to the sustained well-being of urban populations (California State Board of Forestry, Committee on Research 1987). At the university level, Kennedy (1987) stressed that the increased interaction between resource managers and the public makes it even more critical that range conservation students be better educated and role-modeled to understand, appreciate, and master the internal politics of decision-making.

MULTIRESOURCE AND MULTI-AGENCY PLANNING

The management of range vegetation to produce multiple resource outputs was a concern raised by resource managers (USDA Forest Service 1988b). The need to manage forest and rangelands for wild and domestic herbivores was stressed by wildlife and range managers (Flather and Hoekstra in press, USDA Forest Service 1988b). Extensive resource management was seen as an efficient way to ensure water quantity and quality from forest and rangelands (Guldin in press). Not only are these problems multiple-resource oriented, but they are also multi-agency, as land ownerships often form a checkerboard pattern on the landscape.

Issues

The need to address range management from a multiple output perspective has been stressed in this chapter. On public lands, resource managers were concerned that the need to plan for the production of a mix of resource outputs from the land base was not being adequately addressed (Flather and Hoekstra in press, USDA Forest Service 1988b). Problems associated with the timing of management activities or the spatial distribution of these management activities are given insufficient attention because of insufficient time or personnel, or lengthy planning horizons. The loss of habitat on private lands for wildlife species places an increasing importance on nearby public lands to supply food, cover, and water. These remaining lands may have previously supplied only a portion of the total annual feed mix for these wildlife species, and now must supply a year-round feed mix. Examples can be given also where recreational developments on public lands force wildlife onto private lands, resulting in a seasonal forage deficiency, or increased crop damage. Conflicts also exist between wildlife, livestock grazing, and mineral development, and between water rights authority and wildlife in wetland areas. The Forest Service and the BLM must manage for a multiple set of resource outputs, and planning becomes increasingly important to resolve objectives for land management.

Many private landowners are in agreement with the multiple use concept but are concerned with its implementation (Grazing Lands Forum 1987). Specifically, issues of concern included poor enforcement of vandalism laws on private land, economic pressures to convert agricultural lands to developed uses, lack of cooperation between state and federal agencies concerning fish and wildlife habitat, allocation of much of agency funds for single-use management, and economic returns favoring commodity over noncommodity uses (Grazing Lands Forum 1987).

Government crop programs which temporarily change the vegetation composition have an impact on the mix of outputs that can be produced from a landscape composed of many different ownerships (Joyce and Skold 1988). These programs impact the forage and habitat for grazers and browsers, water runoff, and habitat for wildlife. The most recent program, the Conservation Reserve Program, will increase permanent vegetation cover for 10 years by 45 million acres (Chapter 2). State wildlife and fish managers saw this shift in vegetation cover as potentially benefiting small game, and in some places, big game. For the duration of the contract, this land cannot be grazed by livestock. Many questions concerning the impact of this program and future agricultural programs arise. Because these lands potentially represent

a large supply of forage, a concern has been raised on the potential impact on the livestock sector, and on releasing this forage supply at the end of the contract period. In addition, previous research suggests that any gains in wildlife populations would be jeopardized if cover were to shift dramatically after the program was ended (Joyce and Skold 1988).

Opportunities

Many successful examples can be cited where diverse, and often conflicting, interests have been brought together to arrive at common understanding and consensus in planning and implementing multiple uses. These examples include the Coordinated Resource Management Planning programs, the Experimental Stewardship Program, the Northwest Watershed Improvement Coalition, and the Oregon Watershed Improvement Coalition (Demarchi 1988, Grazing Lands Forum 1987).

Oregon range evaluation project—a case study in multiresource planning.—The Accelerated Range Program was initiated to conduct large-scale testing to confirm or adjust multiresource assumptions made in a nationwide study of rangeland productivity (Sanderson et al. 1988). The Grant County Resource Council proposed that Grant County be designated an "evaluation area" under the Forest and Rangeland Renewable Resource Planning Act, and in 1976, Congress appropriated $1.4 million to initiate the Oregon Range Evaluation Project (EVAL). The objective of EVAL was to determine the most cost-effective way to increase herbage and browse for livestock and to determine the effects of range management strategies on water quantity and quality and the consequences for the local economy (Sanderson et al. 1988).

The EVAL project was divided into four major elements: (1) Implementation—selecting private landowners to cooperate with EVAL, developing coordinated resource management plans, and establishing range management practices on public and private land; (2) Maintenance—maintaining the improvements adequately over the study period; (3) Monitoring—collecting baseline data and evaluating the effects of grazing management strategies on environmental, economic, and social resources, and (4) Reporting—providing the research results to all parties (Sanderson et al. 1988). The Forest Service (including the NFS, the State and Private Forestry, and Research) was the lead agency. Primary cooperating agencies and groups included the SCS, the Agricultural Stabilization and Conservation Service, the BLM, Oregon Department of Forestry, Oregon Department of Fish and Wildlife, Oregon State University Extension Service, and private landowners. Many other organizations and institutions cooperated.

The success of the EVAL project is marked by the excellent interagency cooperation and the cooperation provided by the private landowners. The project facilitated the development and implementation of 22 coordinated resource management plans and 21 long-term agreements. Over 1,000 range practices were established on 58,000 acres of private land and on 283,000 acres of public land. More ranchers are now requesting technical assistance than before the EVAL project, and some range practices are being initiated with the benefit of matching funds (Sanderson et al. 1988). The results of more than 100 theses, reports, and publications will provide private landowners, land managers, and environmental groups with economic and environmental information useful in future range management.

Experimental stewardship programs.—Cleary (1988) described the Modoc/Washoe Experimental Stewardship Program in northeastern California and northwestern Nevada as a successful example of coordinated resource management. Participants in this program viewed range management as more comprehensive than livestock management and chose to accommodate all public land uses where possible. Program participants included members from the livestock industry, timber industry, county governments, university range science departments, county Extension Service, SCS, resource conservation districts, Agricultural Stabilization and Conservation Service, Audubon Society, state game departments, state agricultural departments, Fish and Wildlife Service, the National Wildlife Federation, the BLM, and the FS. The long-term goal was to foster cooperation and coordination among the participants to achieve: (1) environmental improvement; (2) integrated and improved management of all ownerships; and (3) through improved management, long-term stability of the economy.

Management and Research Needs

The new and diverse demands being placed on range and forest ecosystems imply a continual need to further understand the ecology of these systems and to develop new management strategies to produce the multiple resource outputs demanded from these wildlands.

Opportunities to address multiple resource planning exist, particularly if state and county coordination can be strengthened (USDA Forest Service 1988b). Demarchi (1988) stated that coordinated resource management planning (CRMP) could be more successful if implemented after the development of a strategic land use plan in which decisions were made concerning the pattern of land use and how much of each use would be allowed within a planning unit. The CRMP focuses on the operational planning, that is, the how and by whom the goals identified in the strategic land use plan are to be achieved.

The desired situation with respect to multiple resource management, as reported in the Grazing Lands Forum (1987), was that all interested groups affected by this type of management would work together voluntarily to share information and arrive at consensus on management action. The recommendations to achieve this situation included: repeatedly invite all interested parties to participate in the planning process, expand the use of successful conflict resolution processes, inform and

assist potential users in conflict resolution, encourage educational and governmental institutions to emphasize multiple use values and coordinated planning, support the development of instructional aids for cooperative multiple use planning, and identify and hold meetings at demonstration sites (Grazing Lands Forum 1987). Opportunities exist also to increase the information transfer between research and management. Demonstration projects such as the EVAL project help increase the flow of research results to management.

Previous research has focused on single resource management and only recently, have multiresource projects begun to unravel the complexities of multiresource production. Research to increase, through cost effective measures, the output of multiple range resources has been recognized as an important research priority (Experiment Station Committee on Organization and Policy 1988, Society for Range Management 1989, Western Agricultural Research Committee 1985). Methods are needed to manipulate the plant community through biological mechanisms such as allelopathy, germplasm improvement, livestock, and introduced competition (Society for Range Management 1989). Also needed is an improved understanding of nutrient cycling processes and critical physiological characteristics of important forest and range plants (Western Agricultural Research Committee 1985).

Understanding and enhancing the productive capabilities of forest and range ecosystems was one of the research issues raised by the Agricultural Experiment Stations (Experiment Station Committee on Organization and Policy 1988). With respect to agricultural and forest land use, the stations saw the need to assess the implication of expanding wildlife enterprises and other recreation uses of agricultural, range, and forest lands, and to develop land use planning systems for the wildlife/rural/urban interface. The implications of changing land use on future forest and rangeland resource production were also identified as an urgent research topic by the California State Board of Forestry (1987). The future size, shape, and distribution of forest and rangeland area will be affected by landowner decisions. How zoning, taxes, population growth, and regulations affect these landowner decisions is not well-understood. Declines in timber and range production by the break-up of commodity-based ownership tracts and by restriction of management practices on and adjacent to residential parcels was a concern of the Board of Forestry (California State Board of Forestry 1987). Smaller parcels and expansion of the urban-wildland interface may reduce wildlife habitat area, create barriers to wildlife migration, enhance sediment losses, and complicate wildfire control problems. Research is needed to determine the long-term trends and to quantify the potential effects on timber and rangeland production, wildlife, rural services, and rural economics (California State Board of Forestry 1987).

Further, the impacts on vegetation are no longer just site-specific. An understanding is needed of the cumulative effects of management within a watershed or a region. Environmental changes, such as increased atmospheric deposition, increased carbon dioxide levels, or elevated air temperatures may have major effects on the structure, function, and productivity of forest and range ecosystems. Future research is needed to understand these possible effects and how forest and range management activities could be altered to sustain forest and range ecosystem health and productivity (Experiment Station Committee on Organization and Policy 1988, USDA Forest Service 1988a).

High-quality data bases and information management systems are needed to permit more knowledgeable policy discussion on land use alternatives (California State Board of Forestry 1988, Experiment Station Committee on Organization and Policy 1988, Flather and Hoekstra in press, USDA Forest Service 1988b). With respect to rangelands, information about the type and condition of vegetation is not complete for all ownerships. This lack of information limits an assessment of the range resource. The Agricultural Experiment Stations identified needed research to understand the biological and ecological concepts applicable to multiuse management of rangelands and pasturelands, and to develop information systems and decision models for users of these lands (Experiment Station Committee on Organization and Policy 1988).

The low economic return on rangelands influences its placement in research priorities. In evaluating the potential success of biological control on pasture/range species, range plants receive a lower priority in research (USDA Agricultural Research Service 1984). In prioritizing the 21 research initiatives, the Agricultural Experiment Stations ranked Productivity of Range and Pastureland the 18th priority, surpassing the initiative on Forest Productivity by only 1 rank (Experiment Station Committee on Organization and Policy 1988). As more resources are demanded from these lands, it will become increasingly important to understand the underlying ecological processes of rangelands.

MANAGEMENT OBSTACLES

Management obstacles are those factors that prevent implementation of effective management opportunities for the range resource. The most common obstacles identified by range resource managers were inadequate funding, inadequate staffing, lack of qualified personnel, and lack of knowledge. These factors were also the most common obstacles cited by wildlife and fish managers (Flather and Hoekstra in press).

Inadequate funding affects all aspects of range management and research. Lack of funds and technology affect the number of management alternatives available to the resource manager. Between 1980 and 1985, in constant (inflation adjusted) dollars, the Forest Service budget declined by 16%, funding for range management on national forests declined by 25%, funding for wildlife and fish management on national forest declined by 9% (Barton and Fosburgh 1986).

Although lack of funding is often the cause for the lack of personnel, declining enrollments and number of graduates with natural resource degrees has resulted in

a short supply of potential resource managers. In addition, specialists for threatened and endangered species are also in short supply. An interdisciplinary approach in planning requires management experts in a variety of fields. Traditional attitudes of personnel/public limit new and creative approaches to land management.

The need for knowledge to provide the best management was discussed in the opportunities sections above. Overcoming this lack of knowledge requires research and the transfer of research results to managers. Knowledge also refers to the awareness and understanding of the public's attitudes and values with respect to the range resource. The need for increased communication between resource managers and the public was recognized as very important. The public must understand the production requirement for a mix of resource outputs and the proposed management for that land. This shared understanding is important to resolve resource conflicts. Public information and education programs, including demonstration projects, are opportunities to increase the communication links. The demands on the range resource are increasingly broadening which expands the number of people and interests using the range resource. Resource managers need to be aware of the changing demand on the range resource to better meet the public's needs.

SUMMARY

Potential shifts in forage production could significantly affect the availability and utilization of forage by wild and domestic herbivores. Increasing demands for recreation and water production from public lands will influence range management. The expected rise in forage demand, coupled with relative declines in public forage and irrigated pastures, suggests that range management on private lands will intensify. A future in which resource use intensifies poses the possibility that our Nation's ecosystems will not likely improve in condition or productivity. The management issues associated with the range resource are now broader than livestock grazing.

Management issues are grouped into four categories: the management of range vegetation; the management of grazers and browsers, both wild and domestic; social issues; and planning. Vegetation management issues revolved around providing the type of vegetation on public and private lands necessary for the production of multiple outputs. Problems ranged from inadequate seasonal forages for wild and domestic herbivores, the expired life-time of existing range improvements, reductions in habitat and forage availability, riparian vegetation, and the control of undesirable plants. Opportunities in vegetation management include grazing systems, stream management for riparian areas, the interseeding of native/introduced species to lengthen the seasonal availability of forage, and the use of biological control agents including livestock. The development and adoption of management practices and technologies will become significant factors in the future of the range resource. Research issues included the lack of knowledge about the ecology of vegetation and the need for technology transfer from research to management.

The need to provide food and habitat for wildlife, wild horses and burros, and livestock raises the issue of the management of grazers and browsers. The number of animals, the seasonal distribution of these animals, the availability of suitable grazers and browsers for each range ecosystem, and the management of these animals on public lands are components of this management issue. Opportunities exist to increase the efficient use of range and forest vegetation and control undesirable plants through the management of multiple species of grazers and browsers.

The value of the natural environment is increasingly in the public's mind, and society's ideas about range will determine the future use of this resource. These social issues point to the need for increased communication between land managers and the public, and for adequately trained range managers. Opportunities exist to communicate the values received from a healthy plant association, the livestock role in maintaining the desired ecological status, and an understanding that proper livestock grazing practices can achieve desired resource benefits.

Whether legally mandated or profit motivated, the desire to produce a mix of resource outputs from forest and rangelands raises the issue of planning. Problems in planning include the design of management for multiple resources, coordination between adjacent or checkerboard ownerships, coordination of timing or spatial distribution of management activities, insufficient planning time, difficulties of quantifying the relationship between current actions and future consequences, economic pressures to convert nonfederal agricultural lands to developed uses, and economic returns favoring commodity over noncommodity uses. Many successful examples can be cited where diverse, and often conflicting, interests have reached consensus in planning and implementing multiple uses.

Research is needed to increase, through cost effective measures, the output of multiple resources from rangelands and forests. Methods are needed to manipulate the plant community through biological mechanisms. Long-term productivity will be sustained only with an improved understanding of nutrient cycling processes, critical physiological characteristics of important forest and range plants, and the response of ecosystems to disturbance.

An understanding is needed of the cumulative effects of management within a watershed, forest, or a region. The future size, shape, and distribution of forest and rangeland area will be affected by land management decisions, and how these decisions are affected by zoning, taxes, population growth, and regulations is not well-understood. Smaller parcels and expansion of the urban/wildland interface may reduce wildlife habitat area, create islands of suitable forage for grazing, create barriers to wildlife migration, increase sediment losses, and complicate wildfire control problems. Research is needed to determine the long-term trends of land use

changes and to quantify the potential effects on rangeland production, wildlife, rural services, and economics. Toward this end, a need exists to develop high-quality data bases, information management systems, and decision models to permit more knowledgeable policy discussion on land use alternatives.

Management obstacles are those factors that prevent implementation of effective management opportunities for the range resource. The most common obstacles identified by range managers were lack of knowledge, inadequate funding, inadequate staffing, and lack of qualified personnel. The actualization of the opportunities for range management requires a commitment of those involved in natural resource management.

CHAPTER 7: IMPLICATIONS OF THE RANGE ASSESSMENT FOR FOREST SERVICE PROGRAMS

RELATIONSHIP BETWEEN ASSESSMENT AND PROGRAM

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), as amended, directs the Secretary of Agriculture to prepare a comprehensive, long-range Assessment of the Nation's renewable resources and to develop a Program for Forest Service activities. The technical supporting documents for range, timber, wildlife, recreation, minerals, and water identify opportunities to balance supplies of renewable resources to meet projected demands. The Assessment presents the findings of these technical supporting documents and summarizes the implications for the Program. Opportunities outlined in the Assessment (Darr in press) help set the scope of the national goals to guide development of the Program. The Program recommends courses of action, based on the findings of the Assessment, for the management and administration of the National Forest System (NFS), for Forest Service Research, and for assistance to state forestry organizations and other cooperators through State and Private Forestry activities. This chapter discusses briefly the implications of this Range Assessment to the 1990 Program of the Forest Service.

FOREST SERVICE PROGRAMS

Forest Service activities are divided into three major areas: National Forest System, State and Private Forestry, and Research. The NFS manages 156 National Forests, 19 National Grasslands, and 16 Land Utilization projects covering a total of 191 million acres. The State and Private Forestry program extends financial and technical assistance to states, and through them, to private landowners, in the application of forest management practices on private lands. Eight Forest Service Experiment Stations and a Forest Products Laboratory conduct research to solve important problems related to the protection, management, and wise use of forest and rangelands through development of knowledge and technology.

The Forest Service receives operating funds from Congress and from various cooperator deposits (USDA Forest Service 1987d). Operations such as timber sales on NFS lands generate receipts. Other receipts from these lands are collected from grazing and recreation fees and mineral leases and permits. In 1986, \$1.32 billion was received from users of NFS lands, while expenditures totaled \$1.71 billion. Eighty-three percent of the revenue in 1986 was from timber receipts which included cash, deposits, and roads in lieu of cash. The second largest source of revenue was receipts from mineral leases, royalties, sales, and bonus bids. Grazing leases provided 1% of the Forest Service revenue (fig. 59).

Expenditures for the NFS measured nearly 83% of the Forest Service budget. The Working Capital Fund which is used to replace vehicles and heavy equipment amounted to 4% of the expenditures; 6% of the expenditures were allocated to Research, and 3% to State and Private Forestry. Human Resource Programs, which expended 4% of the Agency budget, provided job opportunities and training for youths, the unemployed, underemployed, economically disadvantaged, and the elderly, while carrying out high-priority conservation work.

The work force within the Forest Service is distributed across program areas as follows: 92.2% in NFS, 7.3% in Research, and 0.5% in State and Private Forestry (fig. 60). Technical occupations account for 57.3% of the work force; the largest portion is for forestry technicians. Professional staff account for 23.7% of the Agency's work force; foresters and civil engineers are the largest of the professional occupations.

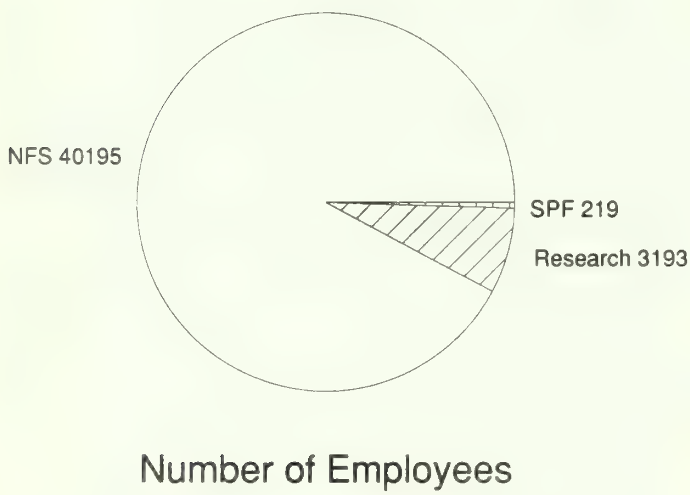
IMPLICATIONS FOR THE 1990 PROGRAM

The 1985 Program provided guidance for the administration of NFS, State and Forestry Programs, Research, and other Forest Service activities through 2030 (USDA Forest Service 1986a). The 1985 RPA Program identified a number of resource options recommended by the Secretary of Agriculture to permit consideration of both the current federal deficit situation and the Forest Service long-term resource goals. These options responded to the long-term renewable resource needs of the American people as described in the Assessment supplement (USDA Forest Service 1984a). The 1985 Program recognized the importance of nonfederal lands in meeting long-term resource needs and emphasized the contribution needed from research to take full advantage of the national resource opportunities.

The specific goal for range identified in the 1985 Program was to "provide forage to promote the economic stability of dependent livestock producers and rural

Source: USDA, Forest Service (1987)

Figure 59.—Distribution of receipts and expenditures by Forest Service program area for 1986.



Source: USDA, Forest Service (1987)

Figure 60.—Distribution of 1986 workforce by Forest Service program area: National Forest System (NFS), State and Private Forestry (SPF), and Research.

communities by maintaining the current level of forage production on National Forest System Lands, and expanding this level of production where cost effective. Develop and apply technology, where cost effective, to improve range conditions and to coordinate livestock and other multiple uses of rangeland'' (USDA Forest Service 1986a).

The first implication of this 1989 Range Assessment for goals set forth in the 1990 Program is that the goals for the range resource must be broadened beyond the traditional value of livestock grazing. Specifically, range resource should be typified by healthy vegetation, the protection of soil and water, the presence of riparian and upland habitat for fish and wildlife species, a land that responds effectively to management improvements, a resource that provides economic benefits and meets public desires for open space. The goal of the Forest Service Program must be directed toward fostering this vision on public lands, and serve as an example for the management of private lands.

National Forest System

Livestock grazing of range forage on NFS lands will continue to contribute to the social and economic well-being of rural communities. Although these traditional values remain, new demands must be accommodated if the Forest Service is to keep pace with changes in society and maintain range productivity. Many demands for the use of range vegetation are recognized in addition to livestock grazing: wildlife habitat, outdoor recreation, hunting, scenery, fresh air and open spaces, places for wild horses to roam, soil stability, water quality and quantity, and minerals.

The Range Assessment has implications for the NFS Program in these general areas:

1. A merging of range science with grazing management so that livestock use becomes a tool for improving vegetation and promoting ecological diversity for a wider variety of uses.
2. Urbanization of areas within and adjacent to the national forests is resulting in land conversion from agricultural use to residential and commercial use. There is a need to resolve the resulting social conflicts, the loss of wildlife habitat and the reduction in opportunities to graze on public lands.

The ultimate goal is to produce quality range vegetation and water on all national forests and grasslands for all resource users within the context of meeting Forest Plan objectives and management requirements. One of the implications of the Wildlife and Fish Assessment is that NFS lands are expected to become more important in the protection and preservation of certain wildlife and fish species, in the preservation and protection of vegetation communities that comprise important wildlife and fish habitat, and in providing wildlife and fish recreational opportunities (Flather and Hoekstra in press). An additional implication of the Wildlife and Fish Assessment is the need to integrate wildlife and fish management considerations into comprehensive land management plans. This challenge will require a commitment across resource lines to provide multiple resource outputs from NFS lands. The future increased demand for range forage will necessitate a cost-efficient and productive grazing program designed to meet future grazing and multiple use needs.

Increased urban and recreational area expansion surrounding NFS lands will require coordinated resource management across a number of ownerships. Without the ability to use interdependent public range, the associated privately owned pasture and cropland will lose their value for agriculture and gain a relatively higher value for commercial and residential development. Because wildlife and fish are mobile resources, one of the major management concerns identified on

public lands was the constraint associated with managing this mobile resource over a land base with intermingled and fragmented land ownership (Flather and Hoekstra in press). Coordinated resource management has been successfully used to address these multiple ownership planning problems (Chapter 6).

The Forest Service must continue to take steps toward a broader view of range management and range management practices—beyond traditional forage and livestock benefits—to an overall perspective that includes a full range of values. To meet these new challenges, the Forest Service is reviewing its range management policy, objectives, and delegations of authority (Comanor 1988a). This examination includes day-to-day operations and methods of range analysis and planning. A full range of values are contemplated to measure range management goals and accomplishments in terms that more accurately portray, both to the administrator and to the public, the broader scope of range vegetation management.

State and Private Forestry

Technical and financial assistance is provided to states by the State and Private Forestry programs to help protect and improve the productivity and management of the nonindustrial private forest lands (USDA Forest Service 1987d). The Cooperative Forestry Assistance Act of 1978 authorized the Secretary of Agriculture to cooperate with state foresters and provide assistance in a variety of forest-related activities: (1) fire prevention and control, (2) prevention and control of forest insects and diseases, and (3) forest management and utilization (USDA Forest Service 1987d). The latter activity can benefit wildlife and range programs through habitat and range improvement programs.

The Range Assessment identified that much of the increase in range forage supply will come from private lands. The Range Assessment also assumed that these private lands will be managed more intensively. The profitability of ranching will determine the actual supply from private lands. The Soil Conservation Service might consider the extent to which technical assistance would facilitate range forage production on private lands. On forested lands, technical assistance through State and Private Forestry programs could expand the implementation of timber management practices in an agroforestry context. The need to diversify outputs from ranching/farming enterprises has led to an interest in multiple use management (Chapter 6). Technical assistance is needed to facilitate the implementation of multiple use management practices on private lands. This implication suggests the need to coordinate resource management among agencies providing technical assistance on rangeland such as the Soil Conservation Service, and the Extension Service.

Forest Service Research

Forest Service research comprises 9 major areas of research: forest fire and atmospheric sciences; forest insect and disease; forest inventory and analysis; renewable resources economics; trees and timber management; watershed and rehabilitation; wildlife, range, and fish habitat; forest recreation; and wood products and harvesting. As required by Title XIV of the Agriculture and Food Act of 1981, Forest Service research is planned jointly with the 61 forestry schools through the USDA Cooperative State Research Service. Research goals are directed toward increasing the productivity of public and private forest and rangeland while maintaining or enhancing environmental quality.

In an official policy paper released by the Secretary's (Agriculture) Office of Science and Education on March 22, 1982, the following responsibilities were stressed by the Administration and Congress as appropriate Federal agricultural research responsibilities:

a. Fundamental approaches that are beyond the risk-taking capacity of the private sector.
b. Areas needing systems approaches, high-cost integrated multidisciplinary approaches, or mega-problems (national/global scope) which are beyond the capability of other sectors.
c. Programs that other areas will not address or which cannot be equally or better accomplished elsewhere. This particularly relates to industry capability and responsibility.
d. Programs which because of their high cost, high priority, or regional, national, or global scale require government management and leadership but do not preclude participation by other sectors.
e. Programs mandated by Congress.
f. Programs required by U.S. Department of Agriculture, such as technical and educational support for action agencies.

Based on this policy statement, the 1985 Program Update concluded that high-priority Forest Service research should be continued, with focus on new research such as biotechnology and more fundamental research, improved information and analytical systems for analysis of domestic and international timber supply-and-demand trends, and research requiring major integrated multidisciplinary efforts of national or international scope. Other major focus points included economic efficiency of forest resource management, atmospheric deposition, water quality and yield, and forest resource protection from fire, insects, and disease (USDA Forest Service 1986a). Research direction identified for range was as follows:

> Greater productivity of range resources is needed and can be realized through genetic improvement of range plants, broader understanding of range ecology, improved grazing management systems, and development of environmentally safe noxious weed control technology.

The Program identified specific opportunities to increase rangeland productivity through research such as forage plant improvement, integration of forage management with other land management strategies, and use of fire for improving rangeland growing conditions (USDA Forest Service 1986a).

This assessment points out the need for greater productivity recognizing the broader demands by the American people on the range resource. Range ecosystems have been managed on the basis of low inputs. Future resource output demands from these systems will require an intensification of management or these systems will not likely improve in condition or productivity. A clear need exists to increase our understanding of basic biological and economic relationships for the purpose of developing new technology to integrate and enhance range resource values on intensively managed rangelands. Low-cost range improvement practices are needed in areas where profit is low. The implications to over-use of the range resources are long-term, particularly in the arid west.

This assessment points out several range research needs:

1. the need to develop vegetation management for multiple resource production from rangelands,
2. the need to define opportunities for multiple grazing species management of rangelands,
3. the need to define the ecological and economical opportunities for using livestock as a vegetation management tool in a broader number of ecosystems,
4. the need to develop quantitative methods to analyze the economic and environmental consequences of increasing multiple resource demand from rangelands on a site-specific basis and at larger scales; this includes the need for better resource inventories,
5. the need to quantify and monitor local and regional impacts of multiple resource management across ownerships.

Range vegetation management must be based on ecological principles and be defined in terms of species composition, ecological condition, and the ability to sustain use. Research needs include understanding of the ecology of rangelands and the ecosystem's response to natural and human-caused disturbances. The nature of human-caused disturbances includes intentional management as well as unintentioned human disturbances, such as the introduction of undesirable plants. The role that biotechnology can play in controlling these disturbances is an important range research goal, as is the role that range vegetation can play in providing genetic material with desired attributes such as drought or pest resistance. The unique aspects of the riparian zone are also a research topic of high priority. Opportunities exist to integrate the disciplines of timber, watershed, wildlife, range, fisheries, and soils research to address the complex interrelationships among plants, animals, and physical factors in riparian zones.

The management of multiple species of grazers and browsers can increase the efficient use of range and forest vegetation. Research needs in this area include the compatibility of animal types, forage requirements, and grazing management systems. Additional research is needed on the economics of multiple species grazing. The role of livestock as a management tool offers opportunities to attain land management objectives, particularly where environmental concerns have shifted the availability of management practices.

As the intensity of land use increases, so does the need to develop quantitative methods to analyze the consequences of increasing resource demand from rangelands on a site-specific basis and at larger scales. The urban encroachment on rangeland not only increases the conflicts between urban and range land activities, but places increased importance on rangeland for wildlife, livestock, recreation, and water production. Linking site-specific activities within the context of other land uses/management activities at a larger scale (such as a watershed, forest, across ownerships, or within a region) will be important in evaluating the consequences of land management activities on the resource outputs from rangeland. Risser et al. (1984) summarized the need for multiple-scale resource analyses by concluding that informed resource planning can no longer be based solely at the site level, but must develop methodologies for examining the interaction of resources across larger geographic areas or landscapes. Future land management decisions will determine the size, shape, and distribution of parcels of land with forest and range vegetation, and these attributes will determine their future viability for resource production.

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APPENDIX A: COMMON AND SCIENTIFIC NAMES OF PLANTS (PRIMARY SOURCE: USDA SOIL CONSERVATION SERVICE. 1982. NATIONAL LIST OF SCIENTIFIC PLANT NAMES. SCS TP 159 2 VOL.)

Common name	Scientific name
Acacia	*Acacia* spp.
Alder	*Alnus* spp.
Apache pine	*Pinus engelmannii*
Arizona cypress	*Cupressus arizonica*
Ash	*Fraxinus* spp.
Aspen	*Populus tremuloides*
Baldcypress	*Taxodium distichum*
Balsam fir	*Abies balsamea*
Barbwire Russian thistle	*Salsola paulsenii*
Basswood	*Tilia* spp.
Beech	*Fagus grandifolia*
Birch	*Betula* spp.
Bitterbrush	*Purshia tridentata*
Black grama	*Bouteloua eriopoda*
Black oak	*Quercus kelloggii*
Blackbrush	*Coleogyne ramosissima*
Blackgum	*Nyssa sylvatica* var. *sylvatica*
Blue grama	*Bouteloua gracilis*
Blue oak	*Quercus douglasii*
Blue spruce	*Picea mariana*
Bluestem	*Andropogon* spp., *Bothriochloa* spp., *Scizachyrium* spp.
Bristlecone pine	*Pinus aristata*
Buffalo gourd	*Cucurbita foetidissima*
Buffalograss	*Buchloe dactyloides*
Buffelgrass	*Cenchrus ciliaris*
Bulrush	*Scirpus* spp.
Burroweed (white bursage)	*Ambrosia dumosa*
Bursage	*Ambrosia deltoidea, A. dumosa*
Canada thistle	*Cirsium arvense*
Canyon live oak	*Quercus chrysolepis*
Ceanothus	*Ceanothus* spp.
Ceniza	*Leucophyllum frutescens*
Cheatgrass	*Bromus tectorum*
Chestnut oak	*Quercus prinus*
Chihuahua pine	*Pinus leiophylla*
Coast live oak	*Quercus agrifolia*
Coastal true fir	*Abies amabilis, A. procera*
Cordgrass	*Spartina patens, S. pectinata*
Cottonwood	*Populus fremontii*
Creosotebush	*Larrea tridentata*
Crested wheatgrass	*Agropyron desertorum*
Cypress	*Taxodium* spp., *Cupressus*
Curly mesquite	*Hilaria belangeri*
Dalmatian toadflax	*Linaria dalmatica*
Diffuse knapweed	*Centaurea diffusa*
Diggerpine	*Pinus sabiniana*
Douglas fir	*Pseudotsuga menziesii*
Dyers woad	*Isatis tinctoria*
Eastern hemlock	*Tsuga canadensis*
Eastern white pine	*Pinus strobus*

Common name	Scientific name
Elm	*Ulmus* spp.
Engelmann spruce	*Picea engelmannii*
Fescue	*Festuca* spp.
Fir	*Abies* spp.
Flowering dogwood	*Cornus florida*
French broom	*Cytisus monspessulanus*
Galleta	*Hilaria* spp.
Gopher plant	*Euphorbia lathyris*
Gorse	*Ulex europaenus*
Grama	*Bouteloua* spp.
Grand fir	*Abies grandis*
Greasewood	*Sarcobatus vermiculatus*
Green ash	*Fraxinus pennsylvanica*
Guayule	*Parthenium argentatum*
Gumweed	*Grindelia* spp.
Halogeton	*Halogeton glomeratus*
Hawthorn	*Crataegus* spp.
Hemlock	*Tsuga* spp.
Hickory	*Carya* spp.
Hoary cress	*Cardaria draba*
Interior live oak	*Quercus wislizenii*
Italian thistle	*Carduus pycnocephalus*
Jack pine	*Pinus banksiana*
Jeffrey pine	*Pinus jeffreyi*
Jojoba	*Simmondsia chinensis*
Juniper	*Juniperus* spp.
Kentucky bluegrass	*Poa pratensis*
Kudzu	*Pueraria lobata*
Larch	*Larix laricina*
Laurel oak	*Quercus laurifolia*
Leafy spurge	*Euphorbia esula*
Lehmans lovegrass	*Eragrostis lehmanniana*
Limber pine	*Pinus flexilis*
Little bluestem	*Schizachyrium scoparium*
Live oak	*Quercus virginiana*
Loblolly pine	*Pinus taeda*
Lodgepole pine	*Pinus contorta*
Longleaf pine	*Pinus palustris*
Longleaf uniola	*Chasmanthium sessiliflorum*
Mangrove	*Avicennia* spp.
Maple	*Acer* spp.
Matchweed (Snakeweed)	*Gutierrezia sarothrae*
Mesquite	*Prosopis juliflora*
Mountain big sagebrush 'Hobble Creek	*Artemesia tridentata* ssp. *vaseyana*
Mountain hemlock	*Tsuga mertensiana*
Musk thistle	*Carduus nutans*
Northern red oak	*Quercus rubra*
Oak	*Quercus* spp.
Overcup oak	*Quercus lyrata*
Paloverde	*Parkinsonia florida, P. microphylum*
Paper birch	*Betula papyrifera*
Pecan	*Carya illinoensis*
Perennial peppergrass	*Lepidium latifolium*
Perennial sowthistle	*Sonchus arvensis*
Persimmon	*Diospyros virginiana*
Pine	*Pinus* spp.
Pinehill bluestem	*Schizachyrium scoparium* var. *divergens*

Common name	Scientific name
Pinyon pine	*Pinus edulis*
Plumeless thistle	*Carduus acanthoides*
Poison hemlock	*Conium maculatum*
Pond cypress	*Taxodium distichum*
Ponderosa pine	*Pinus ponderosa*
Port Orford cedar	*Chamaecyparis lawsoniana*
Post oak	*Quercus stellata*
Prickly pear cactus	*Opuntia* spp.
Purple starthistle	*Centaurea calcitrapa*
Rabbitbrush	*Chrysothamnus* spp.
Red maple	*Acer rubrum*
Red pine	*Pinus resinosa*
Red spruce	*Picea rubens*
Redwood	*Sequoia sempervirens*
Russian knapweed	*Centaurea repens*
Russian thistle	*Salsola iberica*
Sagebrush	*Artemisia* spp.
Saguaro	*Carnegiea* spp.
Saint Johnswort	*Hypericum perforatum*
Saltbush	*Atriplex* spp.
Saltcedar	*Tamarix pentandra*
Saltgrass	*Distichlis spicata*
Sand bluestem	*Andropogon*
Saw grass	*Cladium jamaicense*
Saw palmetto	*Serenoa repens*
Scotch broom	*Cytisus scoparius*
Sedge	*Carex* spp.
Serviceberry	*Amelanchier alnifolia*
Shadscale	*Atriplex confertifolia*
Shin oak	*Quercus mohriana*
Shortleaf pine	*Pinus echinata*
Side oats grama	*Bouteloua curtipendula*
Silver buffaloberry	*Shepherdia argentea*
Sitka spruce	*Picea sitchensis*
Skunkbush sumac	*Rhus trilobata*
Slash pine	*Pinus elliottii*
Slenderflower thistle	*Carduus tenuiflorus*
Smooth brome	*Bromus inermis*
Snakeweed	*Gutierrezia sarothrae*
Snowberry	*Symphoricarpos albus*
Spotted knapweed	*Centaurea maculosa*
Spruce	*Picea* spp.
Subalpine fir	*Abies lasiocarpa lasiocarpa*
Subterranean clover	*Trifolium subterraneum*
Sugar maple	*Acer saccharum*
Sugar pine	*Pinus lambertiana*
Sugarberry	*Celtis laevigata*
Swamp tupelo	*Nyssa sylvatica* var. *biflora*
Sweet bay	*Magnolia virginiana*
Sweetgum	*Liquidambar styraciflua*
Sycamore	*Platanus* spp.
Tall larkspur	*Delphinium* spp.
Tansy ragwort	*Senecio jacobeae*
Tarbush	*Flourensia cernua*
Three awn	*Aristida* spp.
Tobosa	*Hilaria mutica*
Tupelo	*Nyssa* spp.
Valley oak	*Quercus lobata*
Water hickory	*Carya aquatica*

Common name	Scientific name
Water oak	*Quercus nigra*
Water tupelo	*Nyssa aquatica*
Western hemlock	*Tsuga heterophylla*
Western juniper	*Juniperus occidentalis*
Western red cedar	*Thuja plicata*
Western white pine	*Pinus monticola*
Wheatgrass	*Agropyron* spp.
White oak	*Quercus alba*
Willow	*Salix* spp.
Willow oak	*Quercus phellos*
Winterfat	*Eurotia lanata*
Wiregrass	*Aristida stricta*
Yaupon	*Ilex vomitoria*
Yellow birch	*Betula alleghaniensis*
Yellow popular	*Liriodendron tulipifera*
Yellow starthistle	*Centaurea solstitialis*

APPENDIX B: FOREST AND RANGE ECOSYSTEMS

INTRODUCTION

Classification systems have been developed to describe the diversity of vegetation across the Nation's landscape. In this document, forest and range vegetation will be described using the Forest and Range Environmental System (FRES) (Garrison et al. 1977). The relationship between the Society of American Forester's forest types and FRES is presented in Eyre (1980). More detailed forest and range classifications have been developed for specific regions, e.g., for western forest ecosystems (Alexander 1985, Franklin and Dyrness 1973, Johnston 1987, Mauk and Henderson 1984, Pfister et al. 1977) and for eastern forests ecosystems (Braun 1964). FRES types were not defined for Alaska and Hawaii. Forest and rangelands in Alaska have been described by McNicholas (1983). Hawaiian ecosystems have been described by Stone and Scott (1987).

A brief description of the FRES ecosystems is given below. The description of each ecosystem is taken from Garrison et al. (1977), unless otherwise referenced. The broad geographic locations of the FRES ecosystems are mapped in figure 2, and defined in table 1 in Chapter 1. Some of the diverse resource outputs from these ecosystems have been presented in tables 2, 3, and 4 in Chapter 1. More detailed information about fauna found on the nation's forest and rangelands can be found in Flather and Hoekstra (in press) and on timber products from forest lands in Haynes (in press).

EASTERN FOREST ECOSYSTEMS

White-Red-Jack Pine and Spruce-Fir Ecosystems

These forest ecosystems occur in the northeastern part of the Northern region (numbers 10 and 11 in fig. 2). Valued primarily for their timber production, these ecosystems also provide habitat to a variety of wildlife including white-tailed deer, moose, great horned owl, spruce grouse, and ruffed grouse (DeGraaf and Rudis 1986, Eyre 1980). The white-red-jack pine ecosystem also provides habitat for the endangered eastern timber wolf, peregrine falcon, and Kirtland warbler. Insects are important in the nutrient cycling and energy flow of the spruce-fir ecosystem. The spruce budworm, the eastern spruce beetle, and the black-headed budworm feed on needle leaves, and at epidemic levels, may cause serious damage to the forest stand (Shelford 1963). Understory vegetation is predominately shrubs and forbs (Eyre 1980).

Maple-Beech-Birch and Aspen-Birch Ecosystems

These ecosystems commingle along the Canadian border of the Northern region (numbers 18 and 19 in fig. 2). Before European settlement, this area was covered with white-red-jack pine and spruce-fir ecosystems. Paper birch and aspen regenerate on sites disturbed by wildfire or human impact, and are usually succeeded by spruce-fir or pine types, depending upon the location (Eyre 1980). The understory vegetation is typically shrubs or forbs providing good habitat for ruffed grouse, white-tailed deer, and moose (DeGraaf and Rudis 1986), while the cleared areas converted to pasture provide forage for the dairy industry of this region.

Oak-Pine and Oak-Hickory Ecosystems

These ecosystems span the central part of eastern United States, occurring in both the Northern and Southern regions (numbers 14 and 15 in fig. 2). Oak-pine forests are characterized by a stand composition of 50% or more in hardwoods and 25-49% in southern pines, mainly shortleaf pine. Grass and forb production is low in oak-pine when tree density is high (Thill and Wolters 1979), but can exceed a half ton per acre when the overstory is reduced by thinning (Wolters et al. 1982). The oak-pine type provides habitat for game species such as white-tailed deer and wild turkey (DeGraaf and Rudis 1986). Six distinctive vegetation communities were defined in the oak-hickory type by Garrison et al. (1977). Under three of these types—the oak savanna, the mosaic of oak-hickory forest and bluestem prairie on the Ozark Plateau, and the Cross Timbers in Texas and Oklahoma—grasses and forbs contribute significantly to understory composition and production. Under proper management, forage production can exceed 2 tons per acre, providing valuable forage for beef operations (Crawford and Porter 1974). The oak-hickory ecosystem provides habitat for game species such as white-tailed deer and mourning dove (Evans and Kirkman 1981) and a number of endangered plants and animals, including the southern bald eagle, red wolf, and the red-cockaded woodpecker.

Loblolly-Shortleaf Pine Ecosystem

This forest ecosystem covers an extensive area in the northern part of the Southern region (number 13 in fig. 2). These forests are characterized by stands in which 50% or more of the stand is loblolly pine, shortleaf pine, or other southern yellow pines, singly or in combination. Because of the large geographic extent of this type, the remaining stand composition is filled with many different kinds of tree associates. The characteristic understory vegetation is a dense stand of hardwoods, shrubs, woody vines, and pine regeneration. Changes in stand

structure resulting from age and management impact the openness of the stand affecting forage production (Grelen 1978), species composition of birds (Hamilton and Yurkunas 1987, Whiting and Fleet 1987), and small mammal populations (Mullin and Williams 1987). Under an open canopy, pinehill bluestem contributes significantly to herbaceous production, and as the stand ages, longleaf uniola begins to dominate with a decline in herbaceous production (Halls and Schuster 1965). This type is prime habitat for white-tailed deer (Thill 1983), wild turkey, bobwhite, and mourning dove.

Longleaf-Slash Pine Ecosystem

This forest ecosystem rings the coastal edge of the Southern region (number 12 in fig. 2). Longleaf pine, slash pine, or both in a stand composition of 50% or more characterizes this ecosystem. Site and geographic location determine the remaining tree stand composition (Eyre 1980). Upland sites include flowering dogwood, other oaks, hickories, yaupon, persimmon, and hawthorn. Wetter sites may be associated with red maple, sweetgum, blackgum, water, and laurel oak. Under periodic flooding, associates will include baldcypress, pondcypress, blackgum, or water tupelo. Understory vegetation consists of grasses and shrubs. Understories in Louisiana, Mississippi, Alabama, and northwest Florida are dominated by bluestem grasses (Grelen 1978). Florida and Georgia sandhills and pine flatwoods have an understory dominated by wiregrass with other species including saw-palmetto (Grelen 1978). Because of the extensive understory of grass, this type is important for livestock grazing. A number of endangered plants and animals occur, including the red-cockaded woodpecker and the Florida panther. Bobwhite and wild turkey are important game birds. Intensive logging, land clearing with subsequent abandonment, fire suppression, and recently, clearcutting have converted many longleaf-slash communities to pure stands of loblolly or slash pine (Eyre 1980, Grelen 1978).

Oak-Gum-Cypress Ecosystem

This Southern region type is characteristic of river flood plains, the cypress savanna west and the mangrove swamps south of the Florida Everglades, and the eastern coast of Florida, Georgia, and the Carolinas (number 16 in fig. 2). Within the river flood plains, common tree associates are broad-leaved deciduous trees such as willow, maple, sycamore, cottonwood, and beech. The mangrove swamp provides habitat for white-tailed deer and many endangered species such as Florida manatee, brown pelican, bald eagle, hawksbill sea turtle, and Atlantic ridley sea turtle (Odum et al. 1982). The cypress savanna is dominated by needle-leaved deciduous trees and some broad-leaved evergreen or deciduous trees and shrubs. White-tailed deer commonly utilize these habitats, along with gray fox, gray squirrel, fox squirrel, and other small mammals. Wild turkey is an important game bird. The flooded areas provide habitat for ibises, cormorants, herons, egrets, and kingfishers. Endangered species include Bachman's warbler, Florida panther, and bald eagle. Much of this area has been converted to either cropland or pasture. In 1977, Garrison et al. (1977) estimated that only the wettest parts of this type remained in forest, about 10%.

Elm-Ash-Cottonwood Ecosystem

This riparian vegetation type forms narrow corridors on the lower terraces and flood plains of the Mississippi, Missouri, Platte, Kansas, Arkansas, and Ohio Rivers (number 17 in fig. 2). Low to tall broadleaved deciduous trees vary from open to dense stands. Common tree associates differ in the northern and southern extents. The cottonwood-willow stage is usually succeeded by birch, maple, and elm species in the north and sycamore, pecan, elm, sugarberry, or green ash species in the south (Eyre 1980). This type is utilized by waterfowl such as mallard and wood duck, and other birds such as American woodcock and mourning dove (Evans and Kirkman 1981).

WESTERN FOREST ECOSYSTEMS

Douglas-Fir Ecosystem

This forest ecosystem occurs in the Rocky Mountain, the Pacific North, and the California regions (number 20 in fig. 2). Douglas-fir in the coastal regions occurs with western hemlock and western redcedar, and is not usually classified as a climax species because it is moderately intolerant to the low-light intensities characteristic of these forests. Within the Rocky Mountains, Douglas fir tends to occur in pure stands (Mitchell 1983). Understory vegetation varies with the topographic, climatic, and edaphic conditions of the site and ranges from grass-dominated communities to sites densely vegetated with shrubs to sites with little understory vegetation (Mitchell 1983). Mature stands offer little browse or forage, however forest openings and early seral stages offer habitat for elk, deer, black bear, grizzly bear, blue and ruffed grouse, hawks, owls, and mammalian predators such as mountain lions and bobcats and in the western extent, the endangered American peregrine falcon. The Oregon-listed endangered spotted owl has influenced the management of Douglas-fir lands in the Pacific Coast region (Salwasser 1987, Simberloff 1987). Fire suppression has favored tree regeneration at the expense of shrubs, grasses, and rapid tree growth (Arno and Gruell 1986, Gruell 1983, Wright and Bailey 1982). Under proper management, timber harvesting followed by slash burning opens up the site for range vegetation production, benefiting both wildlife and livestock (Wright and Bailey 1982).

Ponderosa Pine Ecosystem

This forest ecosystem is also widely distributed in all western regions (number 21 in fig. 2). By definition, the ponderosa pine ecosystem contains 50% or more of one of these pines: ponderosa, Jeffrey, sugar, limber, Arizona ponderosa, Apache, or Chihuahua (Garrison et al. 1977). The remaining stand composition varies by geographic region. Historical records indicate that fire kept this ecosystem open and parklike with an excellent ground cover of grasses, sedges, and forbs or with an understory of shrubs (Wright and Bailey 1982). Black bear, mule deer, elk, and mountain lion inhabit this forest type (Short 1983). This ecosystem provides timber, recreation, critical summer forage for livestock operations based at lower elevations, and prime summer range for mule deer and elk.

Fir-Spruce, Hemlock-Sitka Spruce, Western White Pine, and Larch Ecosystems

These forest ecosystems occur in the Rocky Mountains along the northern boundary of the Pacific North and Northern Rocky regions (numbers 23, 24, 22, and 25 in fig. 2). Fir-spruce forests, which also occur further south in the Northern Rocky Mountain region, generally have a dense canopy with little understory vegetation providing little forage for wild or domestic herbivores. Shrubs or forbs constitute the understory under the hemlock-sitka spruce and the western white pine ecosystem and are also found under some fir-spruce types (Eyre 1980). Larch is a seral type, succeeding to grand fir or Douglas-fir (Eyre 1980). These ecosystems are interspersed with meadows and stream bottoms with broad-leaved woody species such as aspen and willows. This mosaic of ecosystems provides habitat for moose, elk, mule deer, and white-tailed deer (Clary 1983). Other mammals include wolverine, lynx, black bear, mountain lion, coyote and, in small numbers, the grizzly bear.

Lodgepole Pine Ecosystem

Widespread over the entire western region, this ecosystem is characterized by a composition of 50% or more of lodgepole pine (number 26 in fig. 2). Understory vegetation is a function of the climatic, topographic, and edaphic characteristics of the site, and the time since the last disturbance (Bartolome 1983). Logging and fire shift understory species composition toward grasses and forbs, reducing shrubs. The 25 million acres dominated by lodgepole pine provide a significant source of forage for wild and domestic animals (Bartolome 1983). The fauna is similar to the Douglas-fir and spruce-fir ecosystems.

Redwood Ecosystem

This forest ecosystem covers a small geographic extent in California and Oregon (number 27 in fig. 2). The dense overstory of redwood (20% or more) may be in association with Douglas-fir and grand fir. Fauna include elk, mountain lion, bobcat, and black bear.

Western Hardwoods

Occurring in the Pacific Coast and Rocky Mountain regions, these forests are characterized by a stand composition of 50% or more of coast live oak, canyon live oak, blue oak, valley oak, interior live oak, or aspen. Understory vegetation is primarily grasses (number 28 in fig. 2). Fauna in the California extent include mule deer, California quail, mountain quail, skunk, and the endangered San Joaquin kit fox. Fauna in the Oregon extent is similar to the California extent, with the addition of more northerly species such as the ruffed grouse. In the Rocky Mountain extent, fauna are similar to the surrounding ecosystems. The aspen ecosystem produces significant amounts of forage in addition to valuable wood fiber in the Rocky Mountain region (Betters 1983).

GRASSLAND AND SHRUBLAND ECOSYSTEMS

Sagebrush Ecosystem

This ecosystem occupies the vast plains and plateaus derived from lava flows, ancient lake beds, and broad basins of alluvium in the Rocky Mountain, and the Pacific Coast regions (number 29 in fig. 2). This broad ecosystem type comprises several different sagebrush communities dominated by either different sagebrush species or by sagebrush and grass species (Blaisdell et al. 1982; West 1983a, 1983b). In the early years of western settlement, this type was severely impacted through grazing, cultivation, and the later abandonment of marginal farms (Blaisdell et al. 1982). Disruption of the fire cycle in the sagebrush ecosystem has led to the annualization of this type (West 1983a, 1983b). Heavy grazing pressure reduced the occurrence of the native perennial grasses, allowing sagebrush to increase. Once established, annual exotic plants such as cheatgrass provide the fine-textured fuel that allows wildfires to spread from shrub to shrub in the dry season (Young et al. 1987). The technology exists to reverse the process of annualization on sites with sufficient annual precipitation, however cheatgrass has expanded its range to include sites in the more arid margins of the Great Basin (Young et al. 1987). The sagebrush ecosystem provides habitat for game species such as sage grouse, pronghorn, and mule deer (McArthur et al. 1978) and habitat for the endangered Utah prairie dog (Garrison et al. 1977). The invasion of cheatgrass has facilitated the successful introduction of the exotic game bird, chukar partridge, which uses cheatgrass as a staple item of its diet (Leopold et al. 1981). Most wild horse herds occupy this type.

Desert Shrub and Southwestern Shrubsteppe Ecosystems

These ecosystems are found in areas of the Rocky Mountain and Pacific Coast regions (numbers 30 and 33 in fig. 2) where precipitation is usually less than 10

inches a year, and the soils are poorly developed (Stoddart et al. 1975). Generally these types are referred to as cold-desert shrublands of the temperate latitudes and hot-desert shrublands of tropical and subtropical areas. The sparse vegetation is dominated by woody plants less than 7 feet in height. Shrub species in the cold desert include shadscale, saltbush, various rabbitbrushes, greasewood, and winterfat with associated grasses and few forb species. The exotic cheatgrass has adapted to produce seed in the brief period during spring when moisture is abundant. The cold-desert shrublands furnish winter grazing for thousands of sheep and cattle (Stoddart et al. 1975) and habitat for the wildlife species such as mule deer, pronghorn, coyote, and collared peccary (Short 1983). Wild horses and burros use this ecosystem as well as the sagebrush and annual grasslands ecosystems (McArthur et al. 1978, Verner and Boss 1980). The hot-desert shrublands of California, Arizona, New Mexico, and Texas are dominated by cresotebush, mesquite, blackbrush, bursage, tarbush, paloverde, and cactus. The dominant grass species of black grama, three-awns, and tobosa are associated with side-oats grama and curly mesquite. Desert mule deer, collared peccary, antelope, desert bighorn sheep, quail, dove, and rabbit are important game species (Martin 1975). The desert tortoise, endangered in California, Nevada, and Arizona, occurs in this ecosystem (Short 1983). Hot-desert shrublands are grazed yearlong by wild and domestic herbivores. This type represents the longest history (400 years) of grazing on this continent (Stoddart et al. 1975). The geographic region within which the ecosystems of southwestern shrubsteppe, desert shrub, desert grassland occur are drained by numerous rivers and streams. Riparian vegetation along these waterways has undergone severe manipulation from water developments, overgrazing, and invasion of exotics such as saltcedar (Swift 1984).

Shinnery Ecosystem

This ecosystem forms a narrow corridor on the sand hills and river dunes along the Canadian River in Texas (number 31 in fig. 2). This midgrass prairie is associated with open to dense stands of broad-leaved deciduous shrubs, primarily shin oak, and occasionally needle-leaved low trees and shrubs. Grass species include little bluestem and side-oats grama, with occasional sand bluestem. Fauna reflect the surrounding ecosystems of plains grasslands, pinyon-juniper, and southwestern shrubsteppe.

Texas Savanna Ecosystem

This high shrub savanna ecosystem varies from dense to open canopies of broad-leaved, deciduous and evergreen low trees and shrubs, and needle-leaved evergreen low trees and shrubs (number 32 in fig. 2). The understory component is short-grass and mid-grass species, including bluestems, three-awns, buffalo grass, gramas, curly mesquite, and tobosa. Mesquite is the dominant shrub, although other shrubs include acacia, live oak, juniper, and ceniza shrub. This ecosystem is noted for the abundance of white-tailed deer, wild turkey (Garrison et al. 1977), and collared peccary (Schmidt and Gilbert 1978). Fox squirrel, ringtail, raccoon, mourning dove, scaled quail, and bobwhite also inhabit this ecosystem.

Chaparral-Mountain Shrub Ecosystem

This ecosystem varies across the Pacific Coast and Rocky Mountain regions within which it occurs (number 34 in fig. 2). The California chaparral is characterized by little summer rainfall and comparatively heavy winter precipitation. Although this ecosystem's chief value is watershed protection, livestock do obtain some forage from the chaparral (Stoddart et al. 1975). Part of the critical habitat for the California condor, now found only in captivity, is within this type. Large portions of this ecosystem have been converted to annual grasslands. In the Rocky Mountain foothills, this type exists as open savannas or dense stands of scrub oak. Found in scattered areas in Utah, Arizona, New Mexico, and Colorado, the mountain brush type occurs as a discontinuous transition zone between coniferous forest and grassland or sagebrush ecosystems. This type is not dominated by a single shrub species but rather the shrubs of serviceberry, ceanothus, and snowberry form open stands under which grasses provide suitable forage for livestock (Stoddart et al. 1975).

Pinyon-Juniper Ecosystem

This type, often adjacent to sagebrush, occupies the eroded and rough dissections of western basins and mountains in all of the western regions (number 35 in fig. 2). Pinyon pine and juniper occur as dense to open woodland and savanna woodland. These tree species may grow to 30 feet tall, but commonly are under 15 feet. Understory vegetation appears to be related to climatic patterns where in the cold winter and dry summer regimes, cool season grasses are found; in dry winter climates, warm season grasses occur; and with moist cool winters, chapparal understories are associated with this type. Livestock grazing has been an important use in this type where forage production may be as much as 600 pounds per acre in open stands. Livestock grazing is usually low-intensity, season-long or year-long (Clary 1987). Although past heavy grazing and the increased tree overstory have reduced the forage production available within this type, prescribed fire can be used to reestablish understory species (Everett 1987). Fauna include mule deer, mountain lion, coyote, bobcat, jackrabbit, and numerous species of birds. Commercial products from the pinyon-juniper woodlands are in greater demand today than 10 years ago (Spang 1987). The multiple use management of this ecosystem includes fuelwood, pine nuts, forage, wildlife habitat,

watershed protection, recreational opportunities, esthetic values, wilderness, and energy and mining activities (Spang 1987, Wagstaff 1987).

Mountain Grassland Ecosystem

Dominated by fescue and wheatgrass bunchgrasses, these grasslands are open untimbered areas surrounded by ponderosa pine, Douglas-fir, or lodgepole pine ecosystems (number 36 in fig. 2). The encroachment of trees is slow because of several factors including strong competition for moisture from the bunchgrasses, low temperatures, and soil heaving (Paulsen 1975). Fauna reflect the surrounding ecosystems. Livestock began grazing these grasslands at higher elevations in Colorado, Wyoming, and Montana over 100 years ago, and by 1900 most were overgrazed. Current use is less than 25% of the former high levels (Paulsen 1975). These grasslands are still important summer ranges for cattle and wildlife, have significance as watersheds for water delivery downstream, and are important recreation areas. Although considered originally part of the mountain grasslands (Garrison et al. 1977), the Palouse prairie is described as an intermountain-bunchgrass type by Stoddart et al. (1975). Unlike the mountain grasslands, the Palouse is a grassland not subject to invasion by trees. As a reflection of the deep soil high in organic matter, much of the Palouse Prairie in Oregon, Washington, and Idaho was plowed for production of small grains (Garrison et al. 1977).

Mountain Meadow Ecosystem

Wet to intermittently wet open sites within the forested zones in western mountains characterize this ecosystem (number 37 in fig. 2). Grasses, sedges, and rushes dominate, and fauna reflect the surrounding ecosystems. This type serves as a source of water, highly productive forage for big game such as mule deer, and elk (Turner and Paulsen 1976), forage for livestock, and recreational activities.

Plains Grassland Ecosystem

The short warm-season grasses of blue grama and buffalo grass dominate this ecosystem found in the Rocky Mountain region (number 38 in fig. 2). These grasses coexist with a minor component of forbs, and shrubs such as juniper, sagebrush, silver buffaloberry, skunkbush sumac, rabbitbrush, and mesquite. Two environmental gradients determine species composition within this type. The temperature gradient increases from north to south and the moisture gradient increases from west to east (Stoddart et al. 1975). Pronghorn, mule deer, white-tailed deer, and white-tailed and black-tailed jackrabbit grazed this vegetation type, while prairie dogs and a variety of small rodents provide food for coyotes and raptors. The greater prairie chicken, and sharptailed grouse are important game species. Grasshoppers annually consume 21 to 23% of available range vegetation (Hewitt and Onsager 1983) and at epidemic levels, can present considerable damage to the forage base. The long-billed curlew was once widely distributed across this region, and its decline has been associated with decreasing short-grass prairie habitat (Kantrud 1982). Although the primary economic use of this ecosystem is livestock grazing, agriculture also has an impact. The conversion of native grassland to cropland, called sodbusting, reached high levels during the late 1970s when a poor livestock economy was coupled with a relatively good grain market (Heimlich 1985, Huszar and Young 1984). This extensive land conversion provided much of the incentive for conservation provisions in the Food Security Act of 1985 (Joyce and Skold 1988). Within the plains grasslands and the prairie ecosystems, major river systems are vegetated by riparian communities such as elm-ash-cottonwood or oak-hickory ecosystems. The relative lack of forest vegetation on the plains makes these riparian communities important to wildlife (Swift 1984). Channelizations of streams, and agricultural developments have significantly reduced the original area of these riparian ecosystems (Swift 1984).

Prairie Ecosystem

This ecosystem (number 39 in fig. 2) is known as the true prairie (Risser et al. 1981). Bluestem grasses dominate and woody vegetation is rare. Some forbs occur. Fauna is similar to the plains grasslands ecosystem. The northern extent of this type, known as the prairie pothole region, is an important breeding ground for migratory waterfowl. Shelterbelt plantings have increased the habitat for birds such as mourning doves. Because of the high soil fertility, much of this type has been converted to cropland. The eastern interface of this ecosystem with the eastern deciduous forests results in a mixing of grasses, shrubs, and some trees in this type. Fire and goats have been used to suppress shrub and tree invasion into the prairie (Wright and Bailey 1982).

Desert Grassland Ecosystem

Blue and black grama, galleta, tobosa, curly mesquite, and several threeawn species are the dominant grasses of this southwestern ecosystem (number 40 in fig. 2). Other grass species vary with the moisture regime of a site. Shrubs, such as creosotebush, burroweed, cactus, and mesquite, have been associated with this type, however, extensive shrub invasion of grasslands has become a widespread phenomenon over the past 100 years (Pieper et al. 1983). Five factors were suggested for the invasion: increased livestock grazing, climatic change, increased competition among plant species, rabbits and rodents, and fire control. Pronghorn, collared peccary, and mourning dove inhabit this ecosystem (Short 1983). Grasshoppers and harvester ants can cause

considerable damage to desert grassland vegetation (Pieper et al. 1983).

Wet Grassland Ecosystem

This diverse type occurs as the wet prairies and marshes along the eastern coast, the Florida Everglades and palmetto prairie, the tule marshes in central California, and the wet grasslands on the floodplains in the Intermountain plateaus (number 41 in fig. 2). Cordgrass, saltgrass, and a few forbs form the coastal grassland ecosystem. Scattered shrubs and low to medium tall trees form the overstory with an understory of wiregrass and saw-palmetto in the palmetto grassland, or sawgrass and three-awn in the Everglades. Tules, other bulrushes, and sedges dominate the landscape in the wet marshes in the intermountain floodplains. Fauna in wet grasslands are as diverse as the grasslands. The Central Valley of California and the coastal marshes of Texas and Louisiana are important habitat for seasonal migrations of waterfowl, including the endangered whooping crane. Klopatek et al. (1979) estimated that by 1974, tule marshes had lost 89% of their original area, the Everglades had been reduced 57%, and the palmetto prairie, 27%. Losses were primarily the result of land conversion to cropland.

Annual Grassland Ecosystem

Introduced annual grasses dominate the vegetation, although forbs and perennial bunchgrasses can also be found in this ecosystem which extends from California north into Oregon (number 42 in fig. 2). Fauna includes mule deer, California quail, and numerous small mammals. Mourning dove is also an important species here (Verner and Boss 1980). Much of this type at lower elevations has been converted to irrigated agricultural land. At higher elevations, use is mainly livestock grazing, some dry farming and, because of the proximity to large metropolitan areas in California, intensive recreational use (California Department of Forestry 1987).

Alpine Ecosystem

This type occurs above timberline in the Rocky Mountain and Pacific Mountain systems (number 43 in fig. 2). Grasses, grasslike species, and forbs predominate. The particular composition reflects the environment of the site which can vary dramatically depending on wind and water stress. Wind swept, highly erosive, dry slopes may have cushion plant communities, whereas depressions in the landscape may form a wet meadow. Lakes and ponds with endemic trout can be found within the type, although many lakes have been stocked with introduced species (Thilenius 1975). Year-round mammals include pika, pocket gopher, and yellow-bellied marmot. An important game bird is the ptarmigan. Mule deer, elk, and mountain sheep use the ecosystem for summer forage. Traditionally, large bands of domestic sheep used this ecosystem in summer. This practice has diminished in use, mainly because of the decline in the range sheep industry. Recreational use consists of hiking, hunting, and fishing during the summer, and skiing during the winter (Thilenius 1975).

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APPENDIX C: ENDANGERED (E) AND THREATENED (T) PLANTS AND THEIR DISTRIBUTION WITHIN THEUNITED STATES AND TERRITORIES.

Species				
Scientific name	Common name	Range	Status	Year listed
Agavaceae-Agave family:				
Agave arizonica	Arizona agave	AZ	E	1984
Aizoaceae-Ice plant family:				
Geocarpon minimum	None	AR, MO	T	1987
Alismataceae-Water-plantain family:				
Sagittaria fasciculata	Bunched arrowhead	NC, SC	E	1979
Amaranthaceae-Amaranth family:				
Achyranthes rotundata	None	HI	E	1986
Annonaceae-Custard-apple family:				
Asimina tetramera	Four-petal pawpaw	FL	E	1986
Deeringothamnus pulchellus	Beautiful pawpaw	FL	E	1986
Deeringothamnus rugelii	Rugel's pawpaw	FL	E	1986
Apiaceae-Parsley family:				
Eryngium constancei	Loch Lomond coyote-thistle	CA	E	1986
Eryngium cuneifolium	Snakeroot	FL	E	1987
Oxypolis canbyi	Canby's dropwort	DE, GA, MD, NC, SC	E	1986
Apocynaceae-Dogbane family:				
Cycladenia humilis var. jonesii	Jones cycladenia	AZ, UT	T	1986
Aquifoliaceae-Holly family:				
Ilex cookii	Cook's holly	Puerto Rico	E	1987
Asclepiadaceae-Milkweed family:				
Asclepias welshii	Welsh's milkweed	UT	T	1987
Aspleniaceae:				
Polystichum aleuticum	Aleutian shield-fern	AK	E	1988
Asteraceae-Aster family:				
Argyroxiphium sandwicense ssp. sandwicense	'Ahinahina (Muana Kea silversword)	HI	E	1986
Bidens cuneata	Cuneate bidens	HI	E	1984
Chrysopsis floridana (= Heterotheca floridana)	Florida golden aster	FL	E	1986
Cirsium vinaceum	Sacramento Mountains thistle	NM	T	1987
Dyssodia tephroleuca	Ashy dogweed	TX	E	1984
Echinacea tennesseensis	Tennessee purple coneflower	TN	E	1979
Enceliopsis nudicaulis var. corrugata	Ash Meadows sunray	NV	T	1985
Erigeron maguirei var. maguirei	Maguire daisy	UT	E	1985
Erigeron rhizomatus	Rhizome fleabane	NM	T	1985
Grindelia fraxinopratensis	Ash Meadows gumplant	CA, NV	T	1985
Hymenoxys acaulis var. glabra	Lakeside daisy	OH	T	1988
Hymenoxys texana	None	TX	E	1986
Liatris helleri	Heller's blazing star	NC	T	1987
Lipochaeta venosa	None	HI	E	1979
Pityopsis ruthii (= Heterotheca ruthii, = Chrysopsis ruthii)	Ruth's golden aster	TN	E	1985
Senecio franciscanus	San Francisco Peaks groundsel	AZ	T	1983
Solidago albopilosa	White-haired goldenrod	KY	T	1988
Solidago shortii	Short's goldenrod	KY	E	1985
Solidago spithamaea	Blue Ridge goldenrod	NC, TN	T	1985
Stephanomeria malheurensis	Malheur wire-lettuce	OR	E	1982
Townsendia aprica	Last Chance townsendia	UT	T	1985
Berberidaceae-Barberry family:				
Mahonia sonnei (= Berberis s.)	Truckee barberry	CA	E	1979
Betulaceae-Birch family:				
Betula uber	Virginia round leaf-birch	VA	E	1978
Bignoniaceae-Bignonia family:				
Crescentia portoricensis	Higuero de Sierra	Puerto Rico	E	1987

Species				
Scientific name	Common name	Range	Status	Year listed
Boraginaceae-Borage family:				
Amsinckia grandiflora	Large-flowered fiddleneck	CA	E	1985
Brassicaceae-Mustard family:				
Arabis mcdonaldiana	McDonald's rock-cress	CA	E	1978
Erysimum capitatum var. angustatum	Contra Costa wallflower	CA	E	1978
Glaucocarpum suffrutescens	Toad-flax cress	UT	E	1987
Lesquerella filiformis	Missouri bladderpod	MO	E	1987
Lesquerella pallida	White bladderpod	TX	E	1987
Thelypodium stenopetalum	Slender-petaled mustard	CA	E	1984
Warea carteri	Carter's mustard	FL	E	1987
Warea amplexifolia	Wide-leaf warea	FL	E	1987
Buxaceae-Boxwood family:				
Buxus vahlii	Vahl's boxwood	Puerto Rico	E	1985
Cactaceae-Cactus family:				
Ancistrocactus tobuschii (= Echinocactus t., Mammillaria t.)	Tobusch fishhook cactus	TX	E	1979
Cereus eriophorus var. fragrans	Fragrant prickly-apple	FL	E	1985
Cereus robinii	Key tree-cactus	FL	E	1984
Coryphantha minima (= C. nellieae, Escobaria n., Mammillaria n.)	Nellie cory cactus	TX	E	1979
Coryphantha ramillosa	Bunched cory cactus	TX	T	1979
Coryphantha robbinsorum (= Cochiseia r., Escobaria r.)	Cochise pincushion cactus	AZ	T	1986
Coryphantha sneedii var. leei (= Escobaria l., Mammillaria l.)	Lee pincushion cactus	NM	T	1979
Coryphantha sneedii var. sneedii (= Escobaria s., Mammillaria s.).	Sneed pincushion cactus	TX, NM	E	1979
Echinocactus horizonthalonius var. nicholii	Nichol's Turk's head cactus	AZ	E	1979
Echinocereus engelmannii var. purpureus	Purple-spined hedgehog cactus	UT	E	1979
Echinocereus fendleri var. kuenzleri (= E. kuenzleri, E. hempelii of authors, not Fobe)	Kuenzler hedgehog cactus	NM	E	1979
Echinocereus lloydii (= E. roetteri var. l.)	Lloyd's hedgehog cactus	TX	E	1979
Echinocereus reichenbachii var. albertii (= E. melanocentrus)	Black lace cactus	TX	E	1979
Echinocereus triglochidiatus var. arizonicus (= E. arizonicus)	Arizona hedgehog cactus	AZ	E	1979
Echinocereus triglochidiatus var. inermis (= E. coccineus var. i., E. phoeniceus var. i.)	Spineless hedgehog cactus	CO, UT	E	1979
Echinocereus viridiflorus var. davisii (= E. davisii)	Davis' green pitaya	TX	E	1979
Neolloydia mariposensis (= Echinocactus m., Echinomastus m.)	Lloyd's Mariposa cactus	TX	T	1979
Pediocactus bradyi (= Toumeya b.)	Brady pincushion cactus	AZ	E	1979
Pediocactus despainii	San Rafael cactus	UT	E	1987
Pediocactus knowltonii (= P. bradyi var. k. Toumeya k.)	Knowlton cactus	NM, CO	E	1979
Pediocactus peeblesianus var. peeblesianus (= Echinocactus p., Navajoa p., Toumeya p., Utahia p.)	Peebles Navaho cactus	AZ	E	1979
Pediocactus sileri (= Echinocactus s., Utahia s.)	Siler pincushion cactus	AZ, UT	E	1979
Sclerocactus glaucus (= Echinocactus g., E. subglaucus, E. whipplei var. g., Pediocactus g., S. franklinii, S. whipplei var. g.)	Uinta Basin hookless cactus	CO, UT	T	1979
Sclerocactus mesae verdae (= Coloradoa m., Echinocactus m., Pediocactus m.)	Mesa Verde cactus	CO, NM	T	1979
Sclerocactus wrightiae (= Pediocactus w.)	Wright fishhook cactus	UT	E	1979
Caryophyllaceae-Pink family:				
Arenaria cumberlandensis	Cumberland sandwort	TN, KY	E	1988
Paronychia chartacea (= Nyachia pulvinata)	Papery whitlow-wort	FL	T	1987
Schiedea adamantis	Diamond Head schiedea	HI	E	1984
Chenopodiacea-Goosefoot family:				
Nitrophila mohavensis	Amargosa niterwort	CA	E	1985
Cistaceae-Rockrose family:				
Hudsonia montana	Mountain golden heather	NC	T	1980
Convolvulaceae-Morning glory family:				
Bonamia grandiflora	Florida bonamia	FL	T	1987

Species				
Scientific name	Common name	Range	Status	Year listed
Crassulaceae-Stonecrop family:				
Dudleya traskiae	Santa Barbara Island liveforever	CA	E	1978
Cucurbitaceae-Gourd family:				
Tumamoca macdougalii	Tumamoc globe-berry	AZ	E	1986
Cupressaceae-Cypress family:				
Cupressus abramsiana	Santa Cruz cypress	CA	E	1987
Cyatheaceae-Tree ferm family:				
Cyathea dryopteroides	Elfin tree fern	Puerto Rico	E	1987
Cyperaceae-Sedge family:				
Carex specuicola	None	AZ	T	1985
Ericaceae-Heath family:				
Arctostaphylos pungens var. ravenii (= A. hookeri ssp. ravenii)	Presidio (= Raven's) manzanita	CA	E	1979
Rhododendron chapmanii	Chapman rhododendron	FL	E	1979
Euphorbiaceae-Spurge family:				
Euphorbia (= Chamaesyce) deltoidea ssp. deltoidea	Spurge	FL	E	1985
Euphorbia (= Chamaesyce) garberi	None	FL	T	1985
Euphorbia skottsbergii var. kalaeloana	Ewa Plains 'akoko	HI	E	1982
Fabaceae-Pea family:				
Amorpha crenulata	Crenulate lead-plant	FL	E	1985
Astragalus humillimus	Mancos milk-vetch	CO, NM	E	1985
Astragalus montii	Heliotrope milk-vetch	UT	T	1987
Astragalus perianus	Rydberg milk-vetch	UT	T	1978
Astragalus phoenix	Ash Meadows milk-vetch	NV	T	1985
Astragalus robbinsii var. jesupi	Jesup's milk-vetch	VT, NH	E	1987
Baptisia arachnifera	Hairy rattleweed	GA	E	1978
Galactia smallii	Small's milkpea	FL	E	1985
Hoffmannseggia tenella	Slender rush-pea	TX	E	1985
Lespedeza leptostachya	Prairie bush-clover	IA, IL, MN, WI	T	1987
Lotus dendroideus ssp. traskiae (= L. scoparius ssp. t.)	San Clemente Island broom	CA	E	1977
Lupinus aridorum	Scrub lupine	FL	E	1987
Mezoneuron kavaiense	Uhiuhi	HI	E	1986
Serianthes nelsonii	Hayun lagu (Guam) Tronkon guafi (Rota)	Guam Rota	E	1987
Trifolium stoloniferum	Running buffalo clover	WV, KY, IN	E	1987
Vicia menziesii	Hawaiian vetch	HI	E	1978
Flacourtiaceae-Flacourtia family:				
Banara vanderbiltii	Palo de Ramon	Puerto Rico	E	1987
Frankeniaceae-Frankenia family:				
Frankenia johnstonii	Johnston's frankenia	TX	E	1984
Gentianaceae-Gentian family:				
Centaurium namophilum	Spring-loving centaury	CA, NV	T	1985
Goodeniaceae-Goodenia family:				
Scaevola coriacea	Dwarf naupaka	HI	E	1986
Hydrophyllaceae-Waterleaf family:				
Phacelia argillacea	Clay phacelia	UT	E	1978
Phacelia formosula	North Park phacelia	CO	E	1982
Hypericaceae-St. Johns-Wort Family:				
Hypericum cumulicola	Highlands scrub hypericum	FL	E	1987
Isoetaceae-Quillwort family:				
Isoetes melanospora	Black-spored quillwort	GA, AL, SC	E	1988
I. tegetiformans	Mat-forming quillwort	GA, AL, SC	E	1988
Lamiaceae-Mint family:				
Acanthomintha obovata ssp. duttonii	San Mateo thornmint	CA	E	1985
Dicerandra cornutissima	Longspurred mint	FL	E	1985
Dicerandra frutescens	Scrub mint	FL	E	1985
Dicerandra immaculata	Lakela's mint	FL	E	1985
Haplostachys haplostachya var. angustifolia	None	HI	E	1979
Hedeoma apiculatum	McKittrick pennyroyal	TX, NM	T	1982
Hedeoma todsenii	Todsen's pennyroyal	NM	E	1981
Pogogyne abramsii	San Diego mesa mint	CA	E	1978

Species		Range	Status	Year listed
Scientific name	Common name			
Scutellaria montana	Large-flowered skullcap	GA, TN	E	1986
Stenogyne angustifolia var. angustifolia	None	HI	E	1979
Lauraceae-Laurel family:				
Lindera melissifolia	Pondberry	AL, AR, FL, GA, LA, MO, MS, NC, SC	E	1986
Liliaceae-Lily family:				
Erythronium propullans	Minnesota trout lily	MN	E	1986
Harperocallis flava	Harper's beauty	FL	E	1979
Trillium persistens	Persistent trillium	GA, SC	E	1978
Trillium reliquum	Relict trillium	AL, SC, GA	E	1988
Loasaceae-Loasa family:				
Mentzelia leucophylla	Ash Meadows blazing star	NV	T	1985
Lythraceae-Loosestrife family:				
Lysimachia aspervlaefolia	Rough-leaved loosestrife	NC, SC	E	1987
Maalvaceae-Mallow family:				
Abutilon menziesii	Ko'oloa'ula	HI	E	1986
Callirhoe scabriuscula	Texas poppy-mallow	TX	E	1981
Hibiscadelphus distans	Kauai hau kuahiwi	HI	E	1986
Iliamna corei	Peter's Mountain mallow	VA	E	1986
Kokia cookei	Cooke's kokio	HI	E	1979
Kokia drynarioides	Koki'o (= hau hele'ula or Hawaii tree cotton)	HI	E	1984
Malacothamnus clementinus	San Clemente Island bush-mallow	CA	E	1977
Sidalcea pedata	Pedate checker-mallow	CA	E	1984
Meliaceae-Mahogany family:				
Trichilia triacantha	Baricao	Puerto Rico	E	1988
Nyctaginaceae-Four-o'clock family:				
Mirabilis macfarianei	MacFarlane's four-o'clock	ID, OR	E	1979
Oleaceae-Olive family:				
Chionanthus pygmaeus	Pygmy fringe tree	FL	E	1987
Onagraceae-Evening-primrose family:				
Camissonia benitensis	San Benito evening-primrose	CA	T	1985
Oenothera avita ssp. eurekensis	Eureka Valley evening-primrose	CA	E	1978
Oenothera deltoides ssp. howellii	Antioch Dunes evening-primrose	CA	E	1978
Orchidaceae-Orchid family:				
Isotria medeoloides	Small whorled pogonia	CT, IL, MA, MD, ME, MI, MO, NC, NH, NJ, NY, PA, RI, SC, VA, VT	E	1982
Spiranthes parksii	Navasota ladies'-tresses	TX	E	1982
Papaveraceae-Poppy family:				
Arctomecon humilis	Dwarf bear-poppy	UT	E	1979
Piperaceae-Pepper family:				
Peperomia wheeleri	Wheeler's peperomia	Puerto Rico	E	1987
Poaceae-Grass family:				
Tuctoria mucronata (= Orcuttia m.)	Solano grass	CA	E	1978
Panicum carteri	Carter's panicgrass	HI	E	1983
Swallenia alexandrae	Eureka Dune grass	CA	E	1978
Zizania texana	Texas wild-rice	TX	E	1978
Polemoniacacea-Phlox family:				
Eriastrom densifolium	Santa Ana wooly-star	CA	E	1987
Polygalaceae-Milkwort family:				
Polygala smallii	Tiny polygala	FL	E	1985
Polygonaceae-Buckwheat family:				
Centrostegia leptoceras	Slender-horned spineflower	CA	E	1987
Eriogonum gypsophilum	Gypsum wild-buckwheat	NM	T	1981
Eriogonum ovalifolium var. williamsiae	Steamboat buckwheat	NV	E	1986
Eriogonum pelinophilum	Clay-loving wild-buckwheat	CO	E	1984
Polygonella basiramia (= Polygonella ciliata var. basiramia)	Wireweed	FL	E	1987

Species				
Scientific name	Common name	Range	Status	Year listed
Primulaceae-Primrose family:				
Primula maguirei	Maguire primrose	UT	T	1985
Ranunculaceae-Buttercup family:				
Aconitum noveboracense	Northern wild monkshood	IA, NY, OH, WI	T	1978
Clematis socialis	Alabama leather flower	AL	E	1986
Delphinium kinkiense	San Clemente Island larkspur	CA	E	1977
Rhamnaceae-Buckthorn family:				
Gouania hillebrandii	None	HI	E	1984
Rosaceae-Rose family:				
Cowania subintegra	Arizona cliffrose	AZ	E	1984
Ivesia eremica	Ash Meadows ivesia	NV	T	1985
Potentilla robbinsiana	Robbins' cinquefoil	NH, VT	E	1980
Prunus geniculata	Scrub plum	FL	E	1987
Rubiaceae-Coffee family:				
Gardenia brighamii	Na'u (Hawaiian gardenia)	HI	E	1985
Rutaceae-Citrus family:				
Zanthoxylum thomasianum	St. Thomas prickly-ash	Puerto Rico, Virgin Islands	E	1985
Santalaceae-Sandalwood family:				
Santalum freycinethianum var. lanaiense	Lanai sandalwood or 'iliahi	HI	E	1986
Sarraceniaceae-Pitcher plant family:				
Sarracenia oreophila	Green pitcher plant	AL, GA, TN	E	1980
Saxifragaceae-Saxifrage family:				
Ribes echinellum	Miccosukee gooseberry	FL, SC	T	1985
Scrophulariaceae-Snapdragon family:				
Amphianthus pusillus	Little amphianthus	GA, AL, SC	T	1988
Castilleja grisea	San Clemente Island Indian paintbrush	CA	E	1977
Cordylanthus maritimus ssp. maritimus	Salt marsh bird's-beak	CA	E	1978
Cordylanthus palmatus	Palmate-bracted bird's-beak	CA	E	1986
Pedicularis furbishiae	Furbish lousewort	ME	E	1978
Penstemon haydenii	Blowout penstemon	NE	E	1987
Solanaceae-Nightshade family:				
Goetzea elegans	Beautiful goetzea, matabuey	Puerto Rico	E	1985
Styracaceae-Styrax family:				
Styrax texana	Texas snowbells	TX	E	1984
Taxaceae-Yew family:				
Torreya taxifolia	Florida torreya	FL, GA	E	1984
Thymelaeaceae:				
Daphnopsis hellerana	None	Puerto Rico	E	1988
Verbenaceae - Verbena family:				
Cornutia obovata	Palo de Nigua	Puerto Rico	E	1988

Source: U.S. Department of Interior, Fish and Wildlife Service (1987, 1988), Endangered Species Technical Bulletin, Vol. 12, 13 (thru July 1988).

APPENDIX D: GLOSSARY

Sources for these definitions are listed at the end of the glossary.

Allelopathy.—Chemical inhibition of plants, through products of metabolism, upon each other.

Allotment.—An area designated for the use of a prescribed number and kind of livestock under one plan of management. May be federal or any combination of federal and private ownerships. May consist of several or only one pasture.

Allotment Management Plan (AMP).—The program of action designated to reach a given set of objectives for a given allotment on public lands. It is prepared and agreed to by the permittee(s) and appropriate agency and prescribes the livestock operations, range improvement practices, and maintenance.

Anadromous.—Migrating from the sea up a river to spawn; example, salmon.

Animal Unit (AU).—One mature cow of approximately 1,000 pounds and its calf, or equivalent. Conversion factors have been developed to equate other animal types to this animal unit.

Animal Unit Month (AUM).—Amount of forage required to sustain one animal unit (AU) for 1 month.

Aquifer.—A geologic formation capable of transmitting water through its pores at a rate sufficient for water supply purposes. Aquifers are usually saturated sands, gravel, fractures, caverns, or vesicular rock.

Arid.—A term applied to regions or climates where lack of sufficient moisture severely limits growth and production of vegetation. Limits of precipitation vary considerably according to temperature conditions, with an upper annual limit for cool regions of 10 inches or less and for tropical regions, 15 to 20 inches.

Assessment regions.—Regions used in this and other technical supporting documents and in the assessment document. See California, Northern, Northern Rocky, Pacific Coast, Pacific North, Rocky Mountain, Southern, and Southwest.

AUM.—See Animal Unit Month.

Biological control.—The control of parasites, plants, or other pests by the introduction, preservation, or facilitation of natural predators, parasites, or other enemies, by sterilization techniques, by the use of inhibitory hormones, or by other biological means.

Biotechnology.—Broadly defined, includes any technique that uses living organisms or processes to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses.

Boxed beef.—Cattle carcasses cut into small portions and boxed at the packing plant. Packing houses previously sold the retailer half or quarter carcasses of beef.

Breeding herd.—The animals retained for breeding purposes to provide for the perpetuation of the herd or band. Excludes animals being prepared for market.

Browse.—That part of leaf and twig growth of shrubs, woody vines, and trees available for animal consumption. Also the act of consuming browse.

California Region.—Assessment region encompassing the state of California. This is the National Forest System Region 5.

Carcass weight.—Weight of slaughtered animal after offal (inedible parts) are removed.

Carrying capacity.—The maximum stocking rate possible without inducing damage to vegetation or related resources. It may vary from year to year on the same area because of fluctuating forage production.

Cattle cycle.—A period of approximately 10 years in which the number of beef cattle is expanded for several consecutive years and then reduced for several years in response to perceived changes in profitability of beef production.

Channelization.—The process of excavating a waterway; straightening a streambed so that water flows more efficiently through an area.

Chaparral.—A shrub community composed of sclerophyllous species.

Climax.—The final or stable biotic community in a successional series which is self perpetuating and in dynamic equilibrium with the physical habitat, the assumed end point in secondary succession.

Cold deserts.—The Intermountain area or Great Basin Desert of North America, usually over 60% of its precipitation is in the form of snow.

Concentrate feed.—Grains or their products and other processed food materials that contain a high proportion of nutrients and are low in fiber and water.

Conservation compliance.—A provision of the 1985 Food Security Act that denies future commodity program benefits to producers who do not have specific conservation plans on highly erodible croplands now in production.

Conservation Reserve Program (CRP).—A provision of the 1985 Food Security Act that pays farmers to convert highly erodible cropland to permanent cover of grasses, shrubs, or trees, and to keep that land in permanent cover for 10 years. The land cannot be grazed by livestock or harvested for commercial purposes.

Constant dollars.—Dollars expressed in terms of purchasing power using a particular year as the standard of comparison, adjusted for inflation or deflation using a national index, such as the GNP index (Gross National Product).

Cool-season grasses.—A grass which generally makes the major portion of its growth during the late fall, winter, and early spring. Cool season plants generally exhibit the C-3 photosynthetic pathway, that is, the pentose phosphate pathway of carbon dioxide assimilation.

Coordinated Resource Management Planning (CRMP).—The process whereby various user groups are involved in discussion of alternative resource uses and collectively diagnose management problems, establish goals and objectives, and evaluate multiple use resource management.

Crop residue.—Plant material available for grazing on land from which a crop has been harvested.

Cropland.—Land under cultivation within the last 24 months including cropland harvested, crop failures, cultivated summer fallow, idle cropland used only for pasture, orchards, and land in soil improving crops, but excluding land cultivated in pasture.

CRP.—See Conservation Reserve Program.

Deeded nonirrigated grazing land.—Land owned as a part of the livestock enterprise that is not irrigated.

Defoliation.—The removal of plant leaves, i.e., by grazing or browsing, cutting, chemical defoliant, or natural phenomena such as hail, fire, or frost.

Demand.—The quantity of product willingly bought per unit of time at a specific price.

Desertification.—The process by which an area or region becomes more arid through loss of soil and vegetative cover.

Disposable personal income.—The amount of income available for spending.

Ecological status.—The present state of vegetation and soil protection of an ecological site in relation to the potential natural community for the site. Vegetation status is the expression of the relative degree to which the kinds, proportions, and amounts of plants in a community resemble that of the potential natural community. If classes are used, they should be described in ecological rather than utilization terms. Soil status is a measure of present vegetation and litter cover relative to the amount of cover needed on the site to prevent accelerated erosion.

Edible weight.—This weight measure excludes all bones, but includes the 1/4- to 1/2-inch of separable fat normally sold on retail cuts of meat such as beef, veal, pork, lamb, and mutton.

Endemic.—Local; native; indigenous.

Ephemeral.—Lasting a very short time; transitory.

Exotic.—An organism or species which is not native to where it is found.

Fed animals.—Livestock, usually cattle, in a feedlot.

Fed beef production.—Feeding of grain and other concentrate feedstuffs to produce slaughter cattle.

Feedlot.—A large plot of land where livestock are fed and fattened before slaughter.

Feral.—Escaped from cultivation or domestication and existing in the wild.

Forage.—Browse and herbage which is available and may provide food for grazing animals or be harvested for feeding.

Forb.—Any broad leafed herbaceous plant other than grasses, sedges, or rushes.

Forest land.—Land that is at least 10% stocked by forest trees of any size, including land that formerly had such a tree cover and that will be naturally or artificially regenerated. Forest land includes areas between heavily forested and nonforested lands that are at least 10% stocked with forest trees. Forest land includes pinyon juniper and chaparral areas in the West.

Grazed roughages.—Forage harvested by grazing or browsing forest, range, or pastureland. Roughages are plant materials containing a low proportion of nutrients per unit of weight and usually bulky and coarse, high in fiber, and low in total digestible nutrients.

Grazinglands.—A collective term that includes all lands having plants harvestable by grazing without reference to land tenure, other land uses, management, or treatment practices. Grazinglands include rangelands, transitory range, and forest lands which are suitable for grazing.

Grazing lease.—A document authorizing use of the public lands for the purpose of grazing livestock.

Habitat.—Place where an animals finds the required arrangement of food, cover, and water to meet its biological needs.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Harvested forages.—Forage mechanically harvested from pasturelands or haylands.

Heifer.—A cow that has not produced a calf and is under 3 years of age.

Herbaceous.—Vegetative growth with little or no woody component.

Herbage.—The above-ground biomass of herbaceous plants regardless of grazing preference or availability.

Herbicide.—Any chemical which is toxic to plants.

Herbivore.—Animals that subsist principally or entirely on plants or plant materials. Herbivores include domestic and wild grazers.

Human-related land use.—Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; school yards; roads; railroads; airports; beaches; rights-of-way; or other nonforest land not included in any other specified land use class.

Joint production.—Multiple outputs, such as wildlife and livestock, produced by combining multiple inputs, or management practices.

Multispecies grazing.—One species following another through the grazing area or two or more species grazing the area in combination.

National Forest System.—A branch of USDA Forest Service that manages and protects 191 million acres of land, including 32 million acres of wilderness.

National Grasslands.—Lands administered by the Forest Service but are excluded from the definition of rangelands in the Public Rangelands Improvement Act of 1978.

Nominal price.—Price including the real opportunity cost and inflation.

Non-use.—An authorization to refrain from grazing livestock without loss of preference for further consideration.

Northern Region.—Assessment region encompassing the states of Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, Ohio, West Virginia, Pennsylvania, Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine. This is National Forest System Region 9.

Northern Rocky Region.—Assessment region encompassing the states of Idaho, Montana, North Dakota, Wyoming, South Dakota, Nebraska, Kansas, Colorado, Utah, and Nevada. This is National Forest System Regions 1, 2, and 4.

Noxious.—Harmful or injurious to health or physical well-being; with the passage of the Noxious Weed Act, the term "noxious weed" has become a legal term referring only to those species designated by the Secretary of Agriculture as noxious weeds.

Oregon Range Evaluation Project (EVAL).—A test case in multiresource planning coordinated by numerous state and federal agencies.

Ornamental.—A plant cultivated for decorative purposes.

Pacific Coast Region.—Assessment region combining the Pacific North and California assessment regions.

Pacific North Region.—Assessment region encompassing the states of Oregon and Washington. This is National Forest System Region 6.

Palatability.—The relish with which a particular species or plant part is consumed by an animal.

Per capita.—Per person.

Perennial.—A woody or herbaceous plant living from year to year, not dying after one flowering.

Permit.—A document authorizing use of the public lands for the purpose of grazing livestock; grazing lease.

Pesticide.—A chemical agent such as herbicide, fungicide, insecticide, etc., used for control of specific organisms.

PNC.—See Potential Natural Community.

Potential Natural Community (PNC).—The biotic community that would become established if all successional sequences were completed without interferences by humans under the present environmental conditions.

Primary production.—The conversion of solar energy to chemical energy through the process of photosynthesis. It is represented by the total quantity of organic material produced with a given period by vegetation.

Private grazing land lease rate.—Price paid for the private rental arrangement between a rancher and a landowner.

Range betterment funds.—Portion of grazing fees paid that is prescribed to be used for range improvements.

Range condition.—A term relating to the present status of a unit of rangeland in terms of specific values or potentials. Specific definitions differ by agency.

Rangeland.—A type of land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs. Rangelands include natural grasslands, shrublands, savannas, most deserts, tundra, alpine plant communities, coastal marshes, wet meadows, riparian ecosystems, and plant communities dominated by introduced species.

Range improvement.—Any activity or program on or relating to rangelands which is designed to improve production of forage, change vegetation composition, control patterns of use, provide water, stabilize soil and water conditions, and provide habitat for livestock and wildlife. The term includes, but is not limited to, structure, treatment projects, and use of mechanical means to accomplish the desired result.

Range vegetation.—Plant species of grasses, grass-like plants, forbs, and shrubs. Range vegetation is most commonly associated with grassland and shrubland ecosystems, but is also found in many forest ecosystems.

Range vegetation management.—The management of range vegetation for multiple outputs which include herbaceous and shrub forage for both domestic and wild animals, water quality and quantity, air quality, open space, threatened and endangered plants and animals, genetic material, recreational use, plant diversity, community stability, and scenic quality. Management of range vegetation requires the application of knowledge, skills, and techniques based on ecological principles to maintain or reach established vegetative objectives while protecting fragile soils. The objectives for range vegetation management are defined in terms of species composition, condition, and the ability to provide a specified sustained level of use. Achievement of these vegetation objectives provides for an integrated mix of related resource uses and values.

Raptor.—Predatory bird.

Research.—A division of USDA Forest Service that develops scientific and technical knowledge to enhance the economic and environmental values of forest and rangelands.

Research Natural Area.—A land management category used by federal agencies to designate lands permanently reserved for research and educational purposes.

Resource value rating.—The value of vegetation present on an ecological site for a particular use or benefit; may be established for each plant community capable of being produced on an ecological site, including exotics or cultivated species.

Rest-rotation grazing system.—A grazing management scheme in which rest periods (no grazing) for individual grazing units are incorporated into a grazing rotation. Rest periods are generally the full growing season to permit seed production, establishment of seedlings, or restoration of plant vigor.

Retail weight.—Fixed percentage of carcass weight, specific to type of animal, and based on historical trends.

Riparian ecosystems.—The abiotic and biotic components found within the area defined by the banks and adjacent areas of water bodies, water courses, seeps, and springs whose waters provide soil moisture sufficiently in excess of that otherwise available locally so as to provide a more moist habitat than that of contiguous flood plains and uplands.

Rocky Mountain Region.—Assessment region that combines Northern Rocky and Southwest Assessment regions.

Roundwood.—Logs, bolts, or other round sections cut from growing stock and nongrowing stock sources such as trees smaller than 5 inches d.b.h.; stumps, tops, and limbs of growing stock trees; rough and rotten trees; dead trees; and trees that grow on land other than timberland.

Ruminant.—Eventoed, hoofed mammal of the suborder *Ruminantia*, comprising cloven-hoofed, cud chewing quadrupeds. Includes cattle, deer, and camels.

Semiarid.—A term applied to regions or climates where moisture is normally greater than under arid conditions, but still definitely limits the production of vegetation. The upper limit of average annual precipitation in the cold, semiarid regions is as low as 15 inches, whereas in warm tropical regions it is as high as 45-50 inches.

Seral.—Refers to species or communities that are eventually replaced by other species or communities with a successional sequence.

Short-duration grazing system.—Grazing management whereby relatively short periods (days) of grazing and associated nongrazing are applied to range or pasture units. Periods of grazing and non-grazing are based upon plant growth characteristics.

Sodbuster.—A provision of the 1985 Food Security Act that causes farmers to become ineligible for price-support payments, farm-storage facility loans, crop insurance, and disaster payments if the farmer plows highly erodible land that is not currently cropped.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Soil bank.—A government program established by the Agricultural Act of 1956; a large scale effort to bring about adjustments between supply and demand for agricultural products by taking farmland out of production.

Southern Region.—Assessment region encompassing the states of Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Alabama, Tennessee, Kentucky, Virginia, North Carolina, South Carolina, Georgia, and Florida. This is National Forest System Region 8.

Southwest Region.—Assessment region encompassing the states of Arizona and New Mexico. This is National Forest System Region 3.

Special management pasture.—An area fenced and managed separately because of different management objectives as in riparian ecosystems.

State and Private Forestry.—A division of the USDA Forest Service that provides technical and financial assistance to states to help increase the productivity of nonindustrial private forest lands to meet projected resource demands.

Stocker cattle.—Cattle (calves and older animals) maintained primarily on pasture, range, or harvested forages to increase weight and maturity before being placed in a feedlot.

Succession.—The gradual process of progressive community change and replacement and modification of the physical environment, leading towards a stable potential natural community.

Supply.—The quantity of a product willingly offered for sale per unit of time at a specific price.

Swampbuster.—A provision of the 1985 Food Security Act that causes farmers to become ineligible for commodity program benefits if the producer drains wetlands.

Tallow.—The harder fat of sheep, cattle, etc., separated by melting from the fibrous and membranous matter naturally mixed with it, and used to make candles, soap, etc.

TAMM.—See Timber Assessment Market Model.

Timber Assessment Market Model (TAMM).—A simulation model that estimates roundwood harvest as a function of changes in timber prices and availability.

Timberland.—Forest land which is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. Areas qualifying as timberland have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.

Timber Resource Inventory Model (TRIM).—A simulation model that projects changes in timber inventory, growth, and harvest.

Transitory range lands.—Lands managed principally for timber production but are suitable for forage production for grazing animals including wildlife and livestock during a period of time following thinning, harvest, or other timber management activity.

TRIM.—See Timber Resource Inventory Model.

Tules.—Bulrushes, large sedges, cattails, and such, collectively.

Understory.—Plants growing beneath the canopy of another plant. Usually refers to grasses, forbs, and low shrubs under a tree or brush canopy.

Urban land.—See Human-related land use.

Warm deserts.—The Mojave, Sonoran, and Chihuahuan deserts of North America; precipitation is in the form of rain.

Warm season grasses.—A grass which makes most or all its growth during the spring, summer, or fall, and is usually dormant in winter. Warm season plants usually exhibit the C-4 photosynthetic pathway, that is the dicarboxylic acid pathway of carbon dioxide assimilation.

Waterfowl.—A water bird, especially a swan, goose, or duck.

Weed.—A plant which is undesirable in light of planned land use or which is unwholesome to rangelands or range animals.

Xeric.—Having very little moisture, tolerating, or adapted to dry condition.

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Forest Service Regions and Assessment Regions

☆U.S. GOVERNMENT PRINTING OFFICE: 1989 773-428-25003

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-181**

An Analysis of the Land Base Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis on pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
General Technical Report RM-181

October 1989

An Analysis of the Land Base Situation in the United States: 1989–2040

Acknowledgments

This study is the product of many people, most of whom are employees of the USDA Forest Service. The names of principal and substantive contributors to the individual chapters are listed below. Without the help of these and other support personnel this document would not have been possible. Their contribution is gratefully acknowledged.

The principal authors of Chapter 1, The National Overview, were James T. Bones, Ann E. Carey, Linda A. Joyce, and Edward F. Schlatterer. Key statistics on the forest resource were compiled by Daniel D. Oswald and Karen Waddell from the RPA national data base.

The principal authors of Chapter 2, The North and Great Plains, were Thomas W. Birch and John S. Spencer, Jr.

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The principal authors of Chapter 5, The Pacific Coast, were Charles L. Bolsinger and Willem W. S. van Hees.

The principal authors of Chapter 6, Other Resources of the Land Base, were James T. Bones, John O. Nordin, and William E. Shands (Conservation Foundation).

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General planning and direction of the study were provided by James T. Bones. John S. Spencer, Jr. contributed significantly by organizing and revising the text. Mary D. Williams provided the primary support for preparation of the text.

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HIGHLIGHTS

National Overview

In 1987, 1.5 billion acres, about 63% of the total land and inland water area of the United States was in forest and rangeland. Forest totals 32% and rangeland totals 34% of the land area.

Most of the Nation's forest and rangelands are in nonfederal ownership. In 1987, about 1 billion acres or 67% of the total were owned by nonfederal public agencies, forest industry, farmers and ranchers, and other private individuals.

The federal lands are administered primarily by two agencies—the Forest Service and the Bureau of Land Management.

The nonfederal forest lands are concentrated in the East, and private rangelands are concentrated in the West.

Most of the Nation's high productivity forest lands are located west of the Cascade Mountains in the Pacific Northwest Region and in the South Central Region. The largest areas of highly productive sites are covered by coastal Douglas-fir and hemlock-Sitka spruce types in the West, and loblolly-shortleaf pine and oak-gum-cypress types in the East.

According to Soil Conservation Service estimates, Montana, South Dakota, and Nebraska lead all states in the area of rangeland in the excellent condition class. Texas, Arizona, and New Mexico contain the largest areas of rangeland in the poor condition class.

The area of highest acidity in rainfall for 1980-1985 is centered in western Pennsylvania, eastern Ohio, and southwestern New York. Airborne pollutants are among the suspected causes of death in high-elevation spruce, of spruce growth decreases, and of eastern and southeastern pine growth decreases.

The North and the Great Plains

The 607.7 million acres of land in the North and Great Plains include 169.8 million acres of forest land, 28% of the total. Much of this forest land, especially in the Northeast, lies close to densely populated areas and receives intensive pressure from a wide array of forest users.

The oak-hickory ecosystem is the largest in the area with 47.8 million acres of unreserved forest land or 29% of the total. Maple-beech-birch is the second largest with 43.4 million acres, followed by spruce-fir with 18.9 million acres, aspen-birch with 17.9 million acres, white-red-jack pine with 13.5 million acres, and elm-ash-cottonwood with 11.9 million acres.

Although there is much variation among states, about 80% of all timberland in the North and Great Plains is held by private individuals or firms. Farmers own more forest land than any other group of individual owners.

The area of timberland in New England and the Middle Atlantic states increased steadily from 1952 to 1987. In the North Central Region and Great Plains Region, trends are mixed.

A total of 78.0 million acres in the North and Great Plains are classified as rangeland. Almost all is in the Great Plains. Ninety-five percent of the rangeland is in nonfederal ownership.

Water areas in the North and Great Plains total 57.8 million acres or 54% of the Nation's water. This is 8.7% of the land and water area of these two Sections.

The South

Forest land totals nearly 200 million acres or 38% of the total land area. If the nontimbered western portions of Texas and Oklahoma are excluded, the percentage of forest increases to 54%.

The South's 62 million acres of pine forest continue as a major source of softwood fiber for the world. About two-thirds of the pine forest is natural in origin with the remainder consisting of planted pine.

Loblolly-shortleaf pine is the South's most prevalent pine ecosystem, accounting for three-fourths of the total pine forest or 46 million acres. Longleaf-slash pine totals 16 million acres and the oak-pine type covers 28 million acres.

Oak-hickory is the South's most extensive ecosystem, covering 71 million acres. Bottomland hardwood types cover 31 million acres.

Private owners control 90% of the timberland in the South, a total of 175 million acres. Nonindustrial private owners control 70% of the South's timberland, and forest industry owners control 20%.

The South has 116 million acres of rangeland, with 83% in Texas and the remainder in Oklahoma and Florida.

Water areas in the South cover 24 million acres or 4% of the total area in the section.

The Rocky Mountains

More than 138 million acres or about 25% of the land area are occupied by forests, predominantly of softwood species. Five forest ecosystems totaling some 112 million acres make up about 80% of the forest land in the Rocky Mountain Region—pinyon-juniper, Douglas-fir, fir-spruce, ponderosa pine, and lodgepole pine.

The ponderosa pine ecosystem covers about 16.5 million acres, nearly half of which is in Arizona and New Mexico. Douglas-fir covers 17.9 million acres, principally in Idaho and Montana. Lodgepole pine covers 14.6 million acres, principally in Idaho, Montana, Wyoming, and central Colorado. Fir-spruce covers 16

million acres of higher elevation sites in the region.

Pinyon-juniper is a woodland ecosystem covering about 47 million acres of dry plateaus and broken tablelands.

Three-fourths of the forest land in the Rocky Mountain region is publicly owned. Federal agencies, principally the Forest Service, administer 94 million acres or two-thirds of the total.

The total rangeland area, including pinyon-juniper and chaparral-mountain scrub forests, is about 336 million acres or 61% of the total land base. The sagebrush type is the second largest range ecosystem in the United States with roughly 105 million acres, most of which occurs in the Rocky Mountain Region. Other important rangeland types include sagebrush, southwestern shrubsteppe, desert shrub, mountain grasslands, mountain meadows, desert grasslands, and plains grasslands.

About 167.4 million acres or 50% of the rangeland in the Rocky Mountain States is in public ownership, mostly in the care of the Bureau of Land Management.

The Rocky Mountain section has the smallest water area—roughly 6 million acres or 1% of the total geographic area.

The Pacific Coast

Forests cover 220 million acres or 39% of the land area of the Pacific Coast states. This is 30% of all the forest land in the Nation. Productive timberland totals about 85 million acres and other forest land about 135 million acres.

Douglas-fir, the most important forest type in terms of timber production, covers about 21 million acres. It is the major type in western Oregon and western Washington.

Fir-spruce is the most extensive forest type covering about 116 million acres, mostly in Alaska's interior. Hemlock-Sitka spruce covers about 16 million acres, 11 million of which are located in southeastern Alaska.

The redwood type covers about 1.2 million acres in California. The ponderosa pine type covers about 14 million acres of the Pacific Coast, and lodgepole pine covers about 3.6 million acres.

The pinyon-juniper woodland type covers about 5 million acres, and chaparral covers about 7.6 million acres, mostly in the mediterranean climatic zone in California.

Of the 220 million acres of forest land in the 5-state area, 72 million acres are privately owned. Of the 145 million acres in public ownership, 46 million are in national forests and 99 million acres are held by various other public agencies. Ownership of forest land in Alaska has changed dramatically in the last decade.

Alaska has about 173 million acres of rangeland, most of which is arctic and alpine tundra. California, Oregon, and Washington together have about 68 million acres of rangeland, including 23 million acres of grassland and 45 million acres of shrubland.

The Pacific Coast states contain 20.1 million acres of water, much of which is in coastal waterways.

Other Resources of the Land Base

There is considerable uncertainty about the extent of the Nation's mineral resources. The areas of highest mineralization are the mountains and basins of the West and the Appalachian chain in the East.

Of 5.7 million acres of land disturbed for mining between 1930 and 1980, about 2.7 million acres or 47% have been reclaimed by industry.

Wetlands have high biological productivity and are important as habitat for wildlife and fish at critical times in their life cycle.

Projecting Land Cover and Use Changes

The total area of forest and rangeland is projected to increase about 2% between 1987 and 2000, and then decrease slightly by 2040. The area of forest land is projected to decline over the projection period, decreasing by 4 percent by 2040. The projected reduction in forest land area will result mainly from conversion to other land uses such as reservoirs, urban expansion, highways, and surface mining.

The projected average annual reduction in United States forest area from 1987 to 2040, about 500,000 acres, is less than that for the period 1970 to 1987, which averaged about 2 million acres per year.

Approximately 40 to 45 million acres of highly erodible land used currently for cropland are projected to be converted to grass cover or trees under the Conservation Reserve Program by the year 2000.

In the North and Great Plains, forest and range area is projected to decline. In the Rocky Mountains, total forest and range area is expected to increase by about 15 million acres by 2040, mostly due to expansion of range area. In the Pacific Coast, forest area is projected to drop by 8 million acres and range area is expected to drop by 9 million acres by 2040.

An Analysis of the Land Base Situation in the United States: 1989–2040

CHAPTER 1: THE NATIONAL OVERVIEW

This chapter contains a national overview of the Nation's land base; the area and location of the forest and rangelands,[1] ownership characteristics, productivity, and use of these important lands that contribute so much to the Nation's wealth and well being. In 1987, 1.5 billion acres, about 63% of the total land and inland water area of the United States was in forest and rangeland (table 1). The remaining area was in cropland, deserts, barrens, improved pastures, reservoirs, and residential and urban sites including golf courses, roads, airports, shopping centers, and industrial sites.

To qualify as forest land the land must be at least 10% stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially reforested. Included are transition zones between heavily forested and nonforested lands that are at least 10% stocked with forest trees, and forest areas adjacent to urban and built-up lands.

Rangeland is land on which the potential natural vegetation is predominantly grasses, grass-like plants, forbs, or shrubs; including land revegetated naturally or artificially that is managed like native vegetation. Rangeland includes natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows that are less than 10% stocked with forest trees of any size.

Water areas include those areas that in the past have been classed as large inland water bodies such as lakes, ponds, and reservoirs greater than 40 acres in size and streams and rivers at least one-eighth of a mile wide; and small water bodies such as lakes and ponds 2 acres and greater in size and rivers and streams that are at least 120 feet wide. Also included are the Great Lakes, and the estuaries of the contiguous States, but not the estuaries of Alaska and Hawaii.

VEGETATION COVER

The vegetation cover of the United States varies greatly and is directly related to the annual precipitation and available moisture. Those areas that receive substantial moisture are predominantly forested, while the arid and semiarid areas support grasses and shrubs and are typically associated with rangeland. The total land base of the Nation is almost evenly divided into rangeland (34%), forest land (32%) and other land (34%), which includes cropland, pasture, developed land, and barren areas (fig. 1). Most of the rangelands are found in the Nation's western states and Alaska. The following four states contain over 50 million acres of rangeland each and account for nearly half of the total range area:

	Million acres
Alaska	173
Texas	96
Nevada	60
New Mexico	51
Total	380

The Rocky Mountain Section (fig. 2) has the greatest amount of range of all the sections. A total of 336 million acres, or 61%, of the total land area is classified as rangeland. In contrast, the sections located east of the Mississippi River are mostly developed for crops or improved pasture or are heavily forested. Florida is the only eastern state with a significant amount of rangeland; but even so, its 4.4 million acres of rangeland represent only 13% of the total land area of the State (fig. 3).

Unlike rangeland, forest land is distributed widely throughout the entire United States. Land east of the Great Plains that has not been cleared for agriculture or other works of man is heavily forested. The high elevation areas of the West that receive ample precipitation and the humid portions of the Pacific Coast are also forested. Aside from the Great Plains and the agriculturally important portions of the central states, forests make up an important component of the vegetation of the Nation (fig. 4). Nebraska and North Dakota currently have the lowest percentage of forest cover (each 1%) and Maine has the highest (90%).

RANGE AND FOREST LAND VEGETATION BASE

Vegetation on range and forest land is a function of the climate, fauna, and soils within the landscape. Classification systems have been developed to describe the diversity of vegetation across the Nation's landscape (Bailey 1978, Garrison et al. 1977, Kuchler 1964). In this document, vegetation on forest and rangeland will be described using the 34 ecosystems of the Forest and Range Environmental System (FRES) (Garrison et al. 1977). Forest ecosystems in this system are aggregations of Forest Service forest types (USDA Forest Service 1967). Throughout this paper the term "forest ecosystem" is synonymous with "forest type." Forest Service Forest Inventory and Analysis Work Units throughout the Nation classify forest land by forest type as part of ongoing state inventories. This classification is based on the tree species that presently occupy the site, rather than on potential species. Rangeland ecosystems are broad groupings of the potential natural vegetation (PNV) communities developed by Kuchler (1964). PNV is the vegetation that would exist at a site today if humans or their impact were removed. The vegetation type, mountain meadow, an

[1] *See Glossary for definition of terms.*

Table 1.—Land and water areas (thousand acres) of the United States, by section, region, and state, 1987

Section, region, and state	Total land and water area	Land: Total land area	Land: Forest and rangeland: Total	Land: Forest and rangeland: Forest[1]	Land: Forest and rangeland: Range-land	Land: Other land	Total water area[2]
North							
Northeast							
Connecticut	3,575	3,090	1,815	1,815	—	1,275	485
Delaware	1,512	1,206	398	398	—	808	306
Maine	21,968	19,732	17,713	17,713	—	2,019	2,236
Maryland	7,797	6,252	2,632	2,632	—	3,620	1,545
Massachusetts	5,942	4,994	3,097	3,097	—	1,897	948
New Hampshire	5,926	5,701	5,021	5,021	—	680	225
New Jersey	5,148	4,648	1,985	1,985	—	2,663	500
New York	34,421	30,273	18,791	18,775	16	11,482	4,148
Pennsylvania	29,456	28,601	16,997	16,997	—	11,604	855
Rhode Island	782	667	399	399	—	268	115
Vermont	6,171	5,915	4,479	4,479	—	1,436	256
West Virginia	15,508	15,406	11,942	11,942	—	3,464	102
Total	138,206	126,486	85,269	85,253	16	41,216	11,721
North Central							
Illinois	37,102	35,531	4,265	4,265	—	31,266	1,571
Indiana	23,269	22,895	4,439	4,439	—	18,456	374
Iowa	35,968	35,746	1,565	1,562	3	34,181	222
Michigan	62,122	36,362	18,220	18,220	—	18,142	25,760
Minnesota	55,369	50,640	16,874	16,583	291	33,766	4,729
Missouri	44,684	44,123	12,632	12,523	109	31,491	561
Ohio	28,615	26,211	7,309	7,309	—	18,902	2,404
Wisconsin	42,391	34,740	15,326	15,319	7	19,414	7,651
Total	329,520	286,247	80,630	80,220	410	205,618	43,272
North Total	467,726	412,733	165,899	165,473	426	246,834	54,993
South							
Southeast							
Florida	39,000	34,533	21,110	16,721	4,389	13,423	4,467
Georgia	37,734	36,837	23,907	23,907	—	12,930	897
North Carolina	33,704	30,990	18,891	18,891	—	12,099	2,714
South Carolina	19,986	19,077	12,257	12,257	—	6,820	909
Virginia	27,038	25,246	15,968	15,968	—	9,278	1,792
Total	157,461	146,682	92,133	87,744	4,389	54,549	10,779
South Central							
Alabama	33,659	32,466	21,725	21,725	—	10,741	1,193
Arkansas	34,233	33,319	17,216	16,987	229	16,103	914
Kentucky	25,835	25,321	12,256	12,256	—	13,065	514
Louisiana	31,820	28,482	14,328	13,883	445	14,154	3,338
Mississippi	31,216	30,160	16,693	16,693	—	13,467	1,056
Oklahoma	44,929	43,939	25,515	7,283	14,232	22,424	990
Tennessee	27,101	26,339	13,258	13,258	—	13,081	762
Texas	172,477	167,685	110,115	13,656	96,459	57,570	3,792
Total	400,272	387,713	227,106	115,741	111,365	160,605	12,559
South Total	557,733	534,395	319,239	203,485	115,754	215,154	23,338
Rocky Mountains and Great Plains							
Rocky Mountains							
Arizona	72,930	72,607	66,648	19,384	47,264	5,959	323
Colorado	66,693	66,249	49,199	21,338	27,861	17,050	444
Idaho	53,493	52,692	43,717	21,818	21,899	8,975	801
Montana	94,064	92,765	71,119	21,910	49,209	21,646	1,299
Nevada	70,581	70,112	69,231	8,928	60,303	881	469
New Mexico	77,845	77,632	69,652	18,526	51,126	7,980	213
Utah	54,343	52,502	48,331	16,234	32,097	4,171	1,841
Wyoming	62,711	62,055	56,025	9,966	46,059	6,030	656
Total	552,660	546,614	473,922	138,104	335,818	72,692	6,046

Table 1.—Continued

Section, region, and state	Total land and water area	Land					Total water area[2]
		Total land area	Forest and rangeland			Other land	
			Total	Forest[1]	Range-land		
Great Plains							
Kansas	52,636	52,228	17,998	1,358	16,640	34,230	408
Nebraska	49,467	49,005	24,565	722	23,843	24,440	462
North Dakota	45,287	44,271	13,143	460	12,683	31,128	1,016
South Dakota	49,462	48,532	26,101	1,687	24,414	22,431	930
Total	196,852	194,037	81,807	4,227	77,580	112,229	2,816
Rocky Mountains and Great Plains Total	749,512	740,651	555,729	142,331	413,398	184,921	8,862
Pacific Coast							
Pacific Northwest							
Alaska	378,243	361,887	301,780	129,045	172,735	60,107	16,356
Oregon	62,225	61,546	50,086	28,055	22,031	11,460	679
Washington	43,669	42,483	29,378	21,856	7,522	13,105	1,186
Total	484,137	465,916	381,244	178,956	202,288	84,672	18,221
Pacific Southwest							
California	101,616	99,773	77,868	39,381	38,487	21,905	1,843
Hawaii	4,146	4,110	1,748	1,748	([3])	2,362	36
Total	105,762	103,884	79,616	41,129	38,487	24,267	1,879
Pacific Coast Total	589,899	569,800	460,860	220,085	240,775	108,939	20,100
United States Total	2,364,870	2,257,578	1,501,727	731,374	770,353	755,847	107,293

[1]Contains transition lands that meet the definition of forest land based on cover characteristics but where the predominant vegetation is grasses and forb plants that are used for grazing. The Soil Conservation Service has classified and reported most of these lands as rangeland. In most cases these are noncommercial timberland ecosystems such as pinyon-juniper, chaparral, and post oak.

[2]Includes Atlantic, Pacific, and Gulf Coastal waters; Chesapeake and Delaware Bays; Long Island and Puget Sounds; New York Harbor; Straits of Juan de Fuca and Georgia; and the Great Lakes. Excludes Alaska and Hawaii.

[3]No estimate of rangeland area in Hawaii was available at the time this table was assembled. A current estimate, however, is 1.4 million acres.

Note: Data may not add to totals because of rounding.

Sources: Rangeland areas — Forest Service—Soil Conservation Service reconciled figures, 1982. Forest land areas—Forest Service RPA data base, 1987.

important type for livestock grazing, was added to Kuchler's system. This amended classification was renamed Potential Natural Communities (PNC) to mark this distinction from Kuchler's system (Mitchell and Joyce 1986).

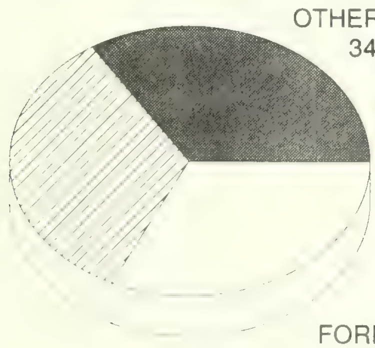


Figure 1.—Distribution of land by use in the United States, 1987.

A brief description of the FRES ecosystems follows.[2] The broad geographic locations are shown within the United States in fig. 5, and defined in table 2. The description of each ecosystem is taken from Garrison et al. (1977) unless otherwise referenced. More detailed information on fauna found on the Nation's forest and rangelands can be found in Flather (in press), and on timber products from forest lands in Haynes (in press).

Eastern Forest Ecosystems

White-red-jack pine and spruce-fir.—These forest ecosystems occur in the northeastern part of the Northern Section (numbers 10 and 11, fig. 5). Valued primarily

[2]The relationship between the Society of American Foresters' forest types and FRES is presented in Eyre (1980). More detailed forest and range classification have been developed for specific regions, e.g. for western forests: Alexander (1985), Barbour and Major (1977), Johnston (1987), Franklin and Dyrness (1973), Mauk and Henderson (1984), Pfister et al. (1977); and for the eastern forests: Braun (1964). FRES types were not defined for Alaska and Hawaii. Forest and rangelands in Alaska were described in McNicholas (1983). Hawaii ecosystems have been described by Stone and Scott (1987).

Figure 2.—Sections and regions of the United States.

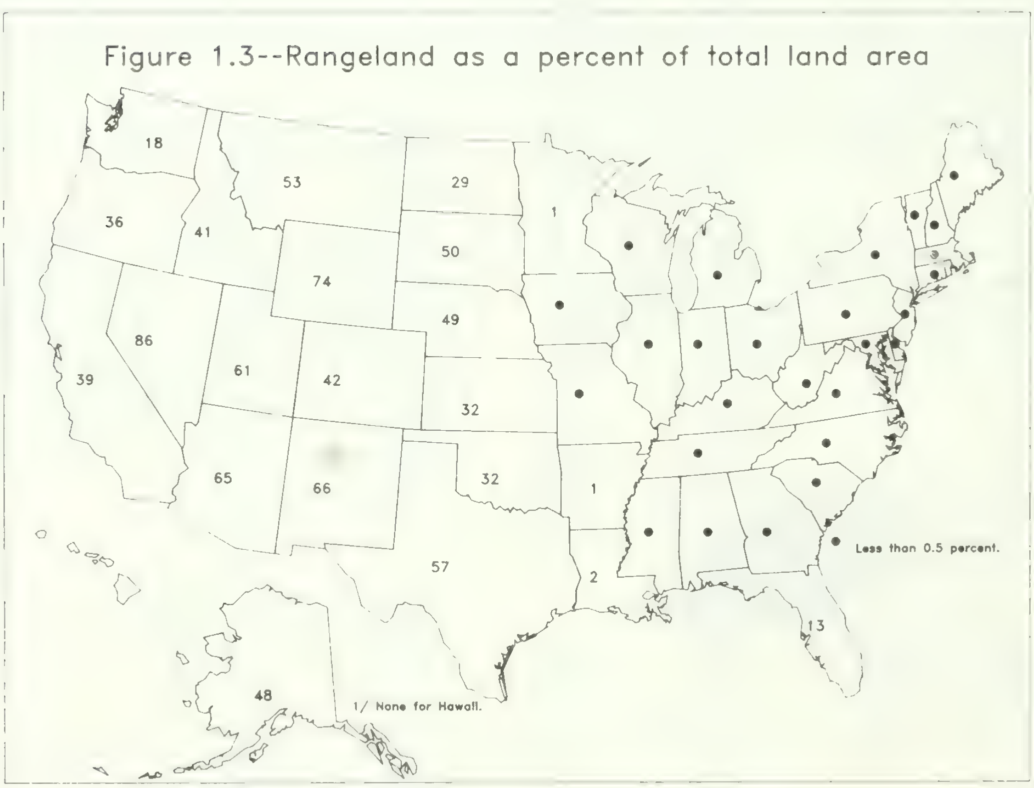


Figure 3.—Rangeland as a percent of total land area by State.

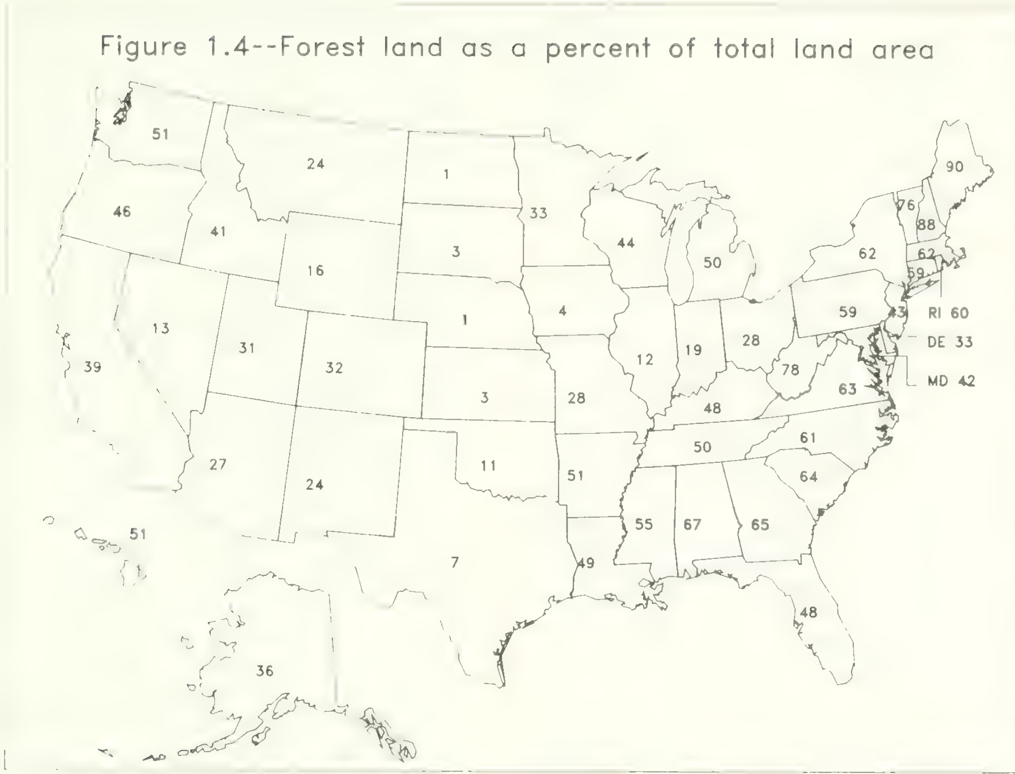
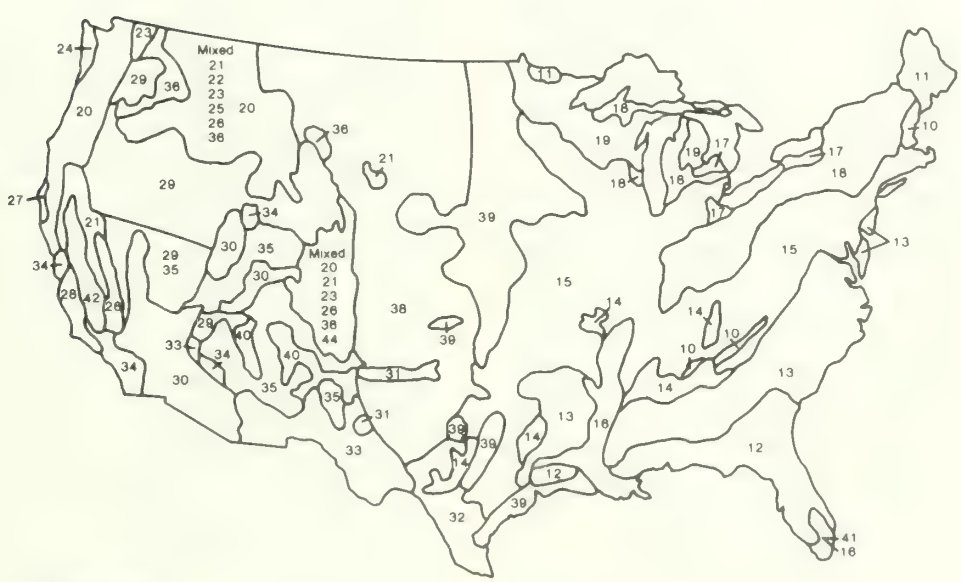


Figure 4.—Forest land as a percent of total land area by State.



[1] Not mapped

Source: Garrison and others 1977

Figure 5.—Forest and range environmental system (FRES) ecosystems of the United States.

Table 2.—Forest and Range Environmental System (FRES) number and ecosystem name

FRES Number	Ecosystem	FRES Number	Ecosystem
10	White-red-jack pine	27	Redwood
11	Spruce-fir	28	Western hardwoods
12	Longleaf-slash pine	29	Sagebrush
13	Loblolly-shortleaf pine	30	Desert shrub
14	Oak-pine	31	Shinnery
15	Oak-hickory	32	Texas savanna
16	Oak-gum-cypress	33	Southwestern shrubsteppe
17	Elm-ash-cottonwood	34	Chaparral-mountain shrub
18	Maple-beech-birch	35	Pinyon-juniper
19	Aspen-birch	36	Mountain grasslands
20	Douglas-fir	37	Mountain meadows[1]
21	Ponderosa pine	38	Plains grasslands
22	Western white pine	39	Prairie
23	Fir-spruce	40	Desert grasslands
24	Hemlock-Sitka spruce	41	Wet grasslands
25	Larch	42	Annual grasslands
26	Lodgepole pine	44	Alpine

[1]*Not mapped*
Source: Garrison et al. 1977.

for their timber production, these ecosystems also contribute habitat to a variety of wildlife including white-tailed deer, moose, great horned owl, spruce grouse, and ruffed grouse (DeGraaf and Rudis 1986, Eyre 1980). The white-red-jack pine ecosystem also provides habitat for the endangered eastern timber wolf, peregrine falcon, and Kirtland warbler. Insects are important in the nutrient cycling and energy flow of the spruce-fir ecosystem. The spruce budworm, the eastern spruce beetle, and the black-headed budworm feed on needle leaves and, at epidemic levels, may cause serious damage to the forest stand (Shelford 1963). Understory vegetation is predominantly shrubs and forbs (Eyre 1980), and these types provide little forage for domestic livestock grazing.

Maple-beech-birch and aspen-birch.—These ecosystems commingle along the Canadian border of the Northern Section (numbers 18 and 19, fig. 5). Prior to European settlement, this area was covered with white-red-jack pine and spruce-fir ecosystems. Paper birch and aspen regenerate on sites disturbed by wildfire or human impact, and are usually succeeded by spruce-fir or pine types if left undisturbed, depending upon the location (Eyre 1980). The understory vegetation is typically shrubs or forbs providing good habitat for ruffed grouse, white-tailed deer, and moose (DeGraaf and Rudis 1986), while the cleared areas converted to pasture provide forage for the dairy industry of this region.

Oak-pine and oak-hickory.—These ecosystems span the central part of eastern United States, occurring in both the North and South Sections (numbers 14 and 15, fig. 5). Oak-pine forests are characterized by a stand composition of 50% or more in hardwoods and 25-49% in southern pines, mainly shortleaf pine. Grass and forb production is low in oak-pine when tree density is high (Thill and Wolters 1979), but can exceed a half ton per acre when the overstory is reduced by thinning (Wolters et al. 1982). The oak-pine type provides habitat for game species such as white-tailed deer and wild turkey (DeGraaf and Rudis 1986). Six distinctive vegetation communities were defined in the oak-hickory type by Garrison et al. (1977). In three of these communities—the oak savanna, the mosaic of oak-hickory forest and bluestem prairie on the Ozark Plateau, and the cross timbers types—grasses and forbs contribute significantly to understory composition and production. Under proper management, forage production can exceed 2 tons per acre, providing valuable forage for beef livestock operations (Crawford and Porter 1974). The oak-hickory ecosystem provides habitat for game species such as white-tailed deer and mourning dove (Evans and Kirkman 1981), and a number of endangered plants and animals, including the southern bald eagle, red wolf, and the red-cockaded woodpecker.

Loblolly-shortleaf pine.—This forest ecosystem covers an extensive area in the northern part of the South Section (number 13, fig. 5). These forests are characterized by stands in which 50% or more of the stand is loblolly pine, shortleaf pine, or other southern yellow pines, singly or in combination. Much of the ecosystem has been converted to pine plantations, often mixed with pasture or row crops. Because of the large geographic extent of this type, the remaining stand composition is filled with many different kinds of trees associates. The characteristic understory vegetation is hardwoods, shrubs, woody vines, and pine regeneration. Changes in stand structure resulting from age and management alter the openness of the stand affecting forage production (Grelen 1978), species composition of birds (Hamilton and Yurkunas 1987, Whiting and Fleet 1987), and small mammal populations (Mullin and Williams 1987). Under an open canopy, pinehill bluestem contributes significantly to herbaceous production, and as the stand ages, longleaf uniola begins to dominate with a decline

in herbaceous production (Halls and Schuster 1965). This type is prime habitat for white-tailed deer (Thill 1983), wild turkey, bobwhite, and mourning dove.

Longleaf-slash pine.—This forest ecosystem rings the coastal edge of the South Section (number 12, fig. 5). A stand composition of 50% or more of longleaf and/or slash pine characterizes this ecosystem. Site and geographic location determine the remaining tree stand composition (Eyre 1980). Upland sites include flowering dogwood, other oaks, hickories, yaupon, persimmon, and hawthorn. Wetter sites may be associated with red maple, sweetgum, blackgum, water and laurel oak. Under periodic flooding, associates will include baldcypress, pondcypress, blackgum, or water tupelo. Understory vegetation consists of grasses and/or shrubby vegetation. Understories in Louisiana, Mississippi, Alabama, and northwest Florida are dominated by bluestem grasses (Grelen 1978). Florida and Georgia sandhills and pine flatwoods have an understory dominated by wiregrass with other species including saw-palmetto (Grelen 1978). Because of the extensive understory of grass, this type is an important ecosystem for domestic livestock grazing. A number of endangered plants and animals occur, including the red-cockaded woodpecker and the Florida panther. Bobwhite and wild turkey are important game birds. Intensive logging, land clearing with subsequent abandonment, fire suppression, and recent clearcutting and regeneration with either loblolly or slash pine have converted many longleaf-slash communities to pure stands of loblolly or slash pine (Eyre 1980, Grelen 1978).

Oak-Gum-Cypress.—This type is found in the Mississippi River flood plain and that of its tributaries as far north as Indiana, along other rivers in the South and Southeast, and in the mangrove swamps of Florida (number 16, fig. 5). Within the river flood plains, common tree associates are broad-leaved deciduous trees such as willow, maple, sycamore, cottonwood, and beech. The mangrove swamp provides habitat for white-tailed deer and for many endangered species such as the Florida manatee, brown pelican, bald eagle, hawksbill sea turtle, and Atlantic ridley sea turtle (Odum et al. 1982). The cypress savanna is dominated by needle-leaved deciduous trees and some broad-leaved evergreen or deciduous trees and shrubs. White-tailed deer commonly utilize these habitats, along with gray fox, gray squirrel, fox squirrel, and other small mammals. Wild turkey is an important game bird. The flooded areas provide habitat for ibises, cormorants, herons, egrets, and kingfishers. Endangered species include Bachman's warbler, Florida panther, and bald eagle. Much of this area has been converted to either cropland or pasture. In 1977, Garrison et al. (1977) estimated that only the wettest parts of this type remained in forest, about 10%.

Elm-ash-cottonwood.—This riparian vegetation type forms narrow corridors on the lower terraces and flood plains of the Mississippi, Missouri, Platte, Kansas, Arkansas, and Ohio Rivers (number 17, fig. 5). Low-to-tall broadleaved deciduous trees vary from open to dense stands. Common tree associates differ in the northern and southern extents. The cottonwood-willow stage is usually succeeded by the Society of American Foresters type birch-maple-elm in the north and by sycamore-pecan-American elm or sugarberry-American elm-green ash in the south (Eyre 1980). This type is utilized by waterfowl and by other birds such as American woodcock and mourning dove (Evans and Kirkman 1981).

Western Forest Ecosystems

Douglas-fir.—This forest ecosystem occurs in the Rocky Mountain and Pacific Coast Sections (number 20, fig. 5). Douglas-fir in the coastal regions occurs with western hemlock and western redcedar, and is not usually classified as a climax species because it is moderately intolerant to the low-light intensities characteristic of these forests. Within the Rocky Mountains, Douglas-fir tends to occur in pure stands (Mitchell 1983). Understory vegetation varies with the topographic, climatic, and edaphic conditions of the site and ranges from grass-dominated communities and sites densely vegetated with shrubs to sites with little understory vegetation (Mitchell 1983). Mature stands offer little browse or forage; however forest openings and early seral stages offer habitat for elk, deer, black bear, grizzly bear, moose, blue and ruffed grouse, hawks, owls, mammalian predators such as mountain lions and bobcats, and the endangered American peregrine falcon. The spotted owl, endangered in Oregon, has influenced the management of Douglas-fir lands in the Pacific Coast section (Salwasser 1987, Simberloff 1987). Fire suppression has favored tree regeneration at the expense of shrubs, grasses, and rapid tree growth (Arno and Gruell 1986, Gruell 1983, Wright and Bailey 1982). Under proper management, timber harvesting followed by slash burning opens up the site for range vegetation production, benefitting both wildlife and domestic livestock (Wright and Bailey 1982).

Ponderosa pine.—This forest ecosystem is also widely distributed in all western regions (number 21, fig. 5). By definition, the ponderosa pine ecosystem contains 50% or more of one of these pines: ponderosa, Jeffrey, sugar, limber, Arizona ponderosa, Apache, or Chihuahua (Garrison et al. 1977). The remaining stand composition varies by geographic region. Historical records indicate that fire kept this ecosystem open and park-like with an excellent ground cover of grasses, sedges, and forbs, or with an understory of shrubs (Wright and Bailey 1982). Black bear, mule deer, elk and mountain lion inhabit this forest type (Short 1983). This ecosystem provides timber, recreation, critical summer forage for livestock operations based at lower elevations, and prime habitat for mule deer and elk.

Fir-spruce, hemlock-Sitka spruce, western white pine, and larch.—These forest ecosystems occur in the Rocky Mountains along the northern boundary of the Pacific Coast and Rocky Mountain sections (numbers 22, 23, 24 and 25, fig. 5). Fir-spruce forests, which also occur further south in the Rocky Mountain Section, generally have a dense canopy with little understory vegetation, and provide little forage for domestic livestock. Shrubs or forbs

constitute the understory under the hemlock-Sitka spruce and the western white pine ecosystem and are also found under some fir-spruce types. Larch is a seral type, succeeding to grand fir or Douglas-fir (Eyre 1980). These ecosystems are interspersed with meadows or stream bottoms with broad-leaved woody species such as aspen and willows. This mosaic of ecosystems provides habitat for moose, elk, mule deer, and white-tailed deer (Clary 1983). Other mammals include wolverine, lynx, black bear, mountain lion, coyote, and in small numbers, the grizzly bear.

Lodgepole pine.—Widespread over the entire West, this ecosystem is characterized by a composition of 50% or more of lodgepole pine (number 26, fig. 5). Understory vegetation is a function of the climatic, topographic, and edaphic characteristics of the site, and the time since the last disturbance (Bartolome 1983). Logging and fire shift understory species composition toward grasses and forbs, reducing shrubs. The 25 million acres dominated by lodgepole pine provide a significant source of forage for wild and domestic animals (Bartolome 1983). The fauna is similar to the Douglas-fir and spruce-fir ecosystems.

Redwood.—This forest ecosystem covers a small geographic extent in California and Oregon (number 27, fig. 5). The dense overstory of redwood (20% or more) may be in association with Douglas-fir and grand fir. Fauna include elk, mountain lion, bobcat, and black bear.

Western hardwoods.—Occurring in the Pacific Coast and Rocky Mountain sections, these forests are characterized by a stand composition of 50% or more of coast live oak, canyon live oak, blue oak, valley oak, interior live oak, or aspen (number 28, fig. 5). Understory vegetation is primarily grasses. Fauna in the California extent include mule deer, California quail, mountain quail, skunk, and the endangered San Joaquin kit fox. Fauna in the Oregon extent is similar to the California extent, with the addition of more northerly species such as the ruffed grouse. In the Rocky Mountain extent, fauna is similar to the surrounding ecosystems. The aspen ecosystem in the Rocky Mountain section produces significant amounts of forage in addition to the valuable wood fiber (Betters 1983).

Grassland and Shrubland Ecosystems

Sagebrush.—This ecosystem occupies the vast plains and plateaus derived from lava flows, ancient lake beds, and broad basins of alluvium in the Rocky Mountain and Pacific Coast Sections (number 29, fig. 5). Several different sagebrush communities are dominated by either different sagebrush species or by sagebrush and grass species (Blaisdell et al. 1982, West 1983a,b). In the early years of western settlement, this type was severely impacted through grazing, cultivation, and the later abandonment of marginal farms (Blaisdell et al. 1982). Disruption of the fire cycle in the sagebrush ecosystem has led to the encroachment and, in some cases, takeover of annual grasses, primarily cheatgrass (West 1983a,b). Heavy grazing pressure has reduced the occurrence of the native perennial grasses, allowing sagebrush to increase in dominance. Annual exotic plants such as cheatgrass become established and provide the fine-textured fuel in the dry season that allows wildfires to spread from shrub to shrub (Young et al. 1987). The technology exists to reverse the process of annualization on sites with sufficient annual precipitation, however cheatgrass has expanded its range to include sites in the more arid margins of the Great Basin (Young et al. 1987). This ecosystem provides habitat for game species such as sage grouse, pronghorn, and mule deer (McArthur et al. 1987), and habitat for the endangered Utah prairie dog (Garrison et al. 1977). The invasion of cheatgrass has facilitated the successful introduction of the exotic game bird, chukar partridge, which uses cheatgrass as a staple item of its diet (Leopold et al. 1981). This ecosystem type supports the majority of wild horse and burro herds. (West 1983a, b).

Desert shrub and southwestern shrubsteppe.—These ecosystems are found in areas of the Rocky Mountain and Pacific Coast Sections (numbers 30 and 33, fig. 5) where precipitation is usually less than 10 inches a year, and the soils are poorly developed (Stoddart et al. 1975). Generally these types are referred to as cold-desert shrublands of the temperate latitudes and hot-desert shrublands of tropical and subtropical areas. The sparse vegetation is dominated by woody plants less than 7 feet in height. Shrub species in the cold desert include shadscale, saltbush, various rabbitbrushes, greasewood, and winterfat with associated grasses and minimal forb species. The exotic invader cheatgrass has adapted to produce seed in the brief period during spring when moisture is abundant. The cold-desert shrubland furnishes winter grazing for thousands of sheep and cattle (Stoddart et al. 1975) and habitat for wildlife species such as mule deer, pronghorn, coyote, and collared peccary (Short 1983). Feral horses use this ecosystem as well as sagebrush and annual grasslands ecosystems (McArthur et al. 1978, Verner and Boss 1980). The hot-desert shrublands of California, Arizona, New Mexico, and Texas are dominated by creosote bush, mesquite, blackbrush, bursage, tarbush, paloverde and cactus shrub. The dominant grass species of black grama, three-awns, and tobosa are associated with side-oats grama and curly mesquite. Desert mule deer, collared peccary, antelope, desert bighorn sheep, quail, dove, and rabbit are important game species (Martin 1975). The desert tortoise, endangered in California, Nevada and Arizona, also occurs here (Short 1983). Hot-desert shrublands are grazed yearlong by domestic livestock. This type represents the longest history (400 years) of grazing on this continent (Stoddart et al. 1975). The geographic region within which the ecosystems of southwestern shrubsteppe, desert shrub and desert grassland occur are drained by numerous rivers and streams. Riparian vegetation along these waterways has undergone severe manipulation from water developments, overgrazing, and invasion of exotics such as saltcedar (Swift 1984).

Shinnery.—This ecosystem forms a narrow corridor on the sand hills and river dunes along the Canadian River in Texas (number 31, fig. 5). This midgrass prairie

is associated with open to dense stands of broad-leaved deciduous shrubs, primarily shin oak, and occasionally needle-leaved low trees and shrubs. Grass species include little bluestem and side-oats grama, with occasional sand bluestem. Fauna reflect the surrounding ecosystems of plains grasslands, pinyon-juniper, and southwestern shrubsteppe ecosystems.

Texas savanna.—This high shrub savanna ecosystem varies from dense to open canopies of broad-leaved, deciduous and evergreen low trees and shrubs, and needle-leaved evergreen low trees and shrubs (number 32, fig. 5). The understory component is short-grass and mid-grass species, including bluestems, three-awns, buffalo grass, gramas, curly mesquite, and tobosa. Mesquite is the dominant shrub, although other shrubs include acacia, live oak, juniper, and ceniza shrub. This ecosystem is noted for the abundance of white-tailed deer, wild turkey (Garrison et al. 1977), and collared peccary (Schmidt and Gilbert 1978). Fox squirrel, ringtail, raccoon, mourning dove, scaled quail, and bobwhite also inhabit this ecosystem.

Chaparral-mountain shrub.—This ecosystem varies across the Pacific Coast and Rocky Mountain Sections within which it occurs (number 34, fig. 5). The California chaparral is characterized by little summer rainfall and comparatively heavy winter precipitation. While this ecosystem's chief value is watershed protection, some forage is also provided for livestock (Stoddart et al. 1975). Part of the critical habitat for the California condor, now found only in captivity, is within this type. Large portions of this ecosystem have been converted to annual grasslands. In the Rocky Mountain foothills, the scrub oak type occupies areas as open savannas or dense stands of oak. Found in scattered areas in Utah, Arizona, New Mexico, and Colorado, the mountain brush type occurs as a discontinuous transition zone between coniferous forest and grassland or sagebrush ecosystems (Stoddart et al. 1975). This type is not dominated by a single shrub species, but rather the shrubs of serviceberry, ceanothus, and snowberry form open stands under which grasses provide suitable forage for domestic livestock (Stoddart et al. 1975).

Pinyon-juniper.—This type, often adjacent to sagebrush, occupies the eroded and rough dissections of western basins and mountains in all of the western regions (number 35, fig. 5). Pinyon pine and juniper occur as dense to open woodland and savanna woodland. These tree species may grow to 30 feet tall, but commonly are under 15 feet. Understory vegetation appears to be related to climatic patterns in cold winter/dry summer regimes, cool season grasses are found; in dry winter climates, warm season grasses occur; and with moist cool winters, chapparal understories are associated with this type (Clary 1987). Livestock grazing has been an important use in this type where forage production may be as much as 600 pounds per acre in open stands (Clary 1987). Domestic livestock grazing is usually low-intensity, season-long or yearlong (Clary 1987). While past heavy grazing and the increased tree overstory have reduced the forage production available within this type, prescribed fire can be used to reestablish understory species (Everett 1987). Fauna include mule deer, mountain lion, coyote, bobcat, jackrabbit, and numerous species of birds. Commercial products from the pinyon-juniper woodlands are in greater demand today than 10 years ago (Spang 1987). The multiple use management of this ecosystem includes providing fuelwood, firewood, pine nuts, forage, wildlife habitat, watershed protection, recreational opportunities, esthetic values, wilderness, energy and mining activities (Spang 1987, Wagstaff 1987).

Mountain grassland.—Dominated by fescue and wheatgrass bunchgrasses, these grasslands are open untimbered areas surrounded by ponderosa pine, Douglas-fir, or lodgepole pine ecosystems (number 36, fig. 5). The encroachment of trees is slow because of several factors including strong competition for moisture from the bunchgrasses, low temperatures, and soil heaving. Fauna reflect the surrounding ecosystems. Grasslands at higher elevations in Colorado, Wyoming, and Montana were initially grazed 100 years ago and by 1900 most of these grassland were being grazed or were overgrazed. Current use is less than 25% of the former high levels (Paulsen 1975). These grasslands are still important summer ranges for cattle and wildlife, have significance as watersheds for water delivery downstream, and are important recreation areas. While considered originally part of the mountain grasslands (Garrison et al. 1977), the Palouse prairie is described as an intermountain-bunchgrass type by Stoddart et al. (1975). Unlike the mountain grasslands, the Palouse is a grassland not subject to invasion by trees. As a reflection of the deep soil high in organic matter, much of the Palouse Prairie in Oregon, Washington, and Idaho was plowed for production of small grains (Garrison et al. 1977).

Mountain meadow.—Wet to intermittently wet open sites within the forested zones in western mountains characterize this ecosystem (number 37, fig. 5). Grasses, sedges, and rushes dominate, and fauna reflect the surrounding ecosystems. This ecosystem serves as a source of water, yields highly productive forage for livestock and big game such as mule deer and elk (Turner and Paulsen 1976), and supports many recreational activities.

Plains grassland.—The short warm-season grasses of blue grama and buffalo grass dominate this ecosystem found in the Rocky Mountain Section (number 38, fig. 5). These grasses coexist with a minor component of forbs and shrubs, such as juniper, sagebrush, silver buffaloberry, skunkbush sumac, rabbitbrush, and mesquite. Two environmental gradients determine species composition within this type: the temperature gradient, which increases from north to south, and the moisture gradient, which increases from west to east (Stoddart et al. 1975). Pronghorn, mule deer, white-tailed deer, and white-tailed and black-tailed jackrabbit utilize this type. Prairie dogs and a variety of small rodents provide food for coyotes and raptors. The greater prairie chicken and sharptailed grouse are important game species. Grasshoppers annually consume about one-fifth of available range vegetation (Hewitt and Onsager 1983) and, at epidemic levels, can present

considerable damage to the forage base. The long-billed curlew was once widely distributed across this region, and its decline may be associated with decreasing short-grass prairie habitat (Kantrud 1982). The primary economic use of this ecosystem is domestic livestock grazing; however, the conversion of native grassland to agriculture, called sodbusting, reached high levels during the late 1970s when a poor livestock economy was coupled with a relatively good grain market (Heimlich 1985, Huszar and Young 1984). This extensive land conversion provided much of the incentive for conservation provisions in the 1985 Farm Bill (Joyce and Skold 1988). Within the plains grasslands and the prairie ecosystems, riparian communities such as elm-ash-cottonwood or oak-hickory ecosystems occur along major river systems. The relative lack of forest vegetation on the plains makes these riparian communities important to wildlife. Channelizations of streams and agricultural developments have significantly reduced the original area of the riparian ecosystems (Swift 1984).

Prairie.—This ecosystem is known as the true prairie (Risser et al. 1981). Bluestem grasses dominate and woody vegetation is rare. Some forbs occur. Fauna is similar to the plains grasslands ecosystem. The northern extent of this type, known as the prairie pothole region, is an important breeding ground for migratory waterfowl. Shelterbelt plantings have increased the habitat for birds such as mourning doves. Because of high soil fertility, much of this type has been converted to cropland. The eastern interface of this ecosystem with the eastern deciduous forests results in a mixing of grasses, shrubs and some trees in this type (number 39, fig. 5). Fire and goats have been used to suppress shrub and tree invasion into the prairie (Wright and Bailey 1982).

Desert grassland.—Blue and black grama, galleta, tobosa, curly mesquite, and several three-awn species vary with the moisture regime of a site (number 40, fig. 5). Shrubs, such as creosote bush, burroweed, cactus, and mesquite have been associated with this type, however, shrub invasion of grasslands has become a widespread phenomenon over the past 100 years (Pieper et al. 1983). Five factors are suggested for the invasion: increased livestock grazing, climatic change, increased competition among plant species, rabbits and rodents, and fire control. Pronghorn, collared peccary and mourning dove inhabit this ecosystem (Short 1983). Grasshoppers and harvester ants can cause considerable damage to desert grassland vegetation (Pieper et al. 1983).

Wet grasslands.—This diverse type occurs as the wet prairies and marshes along the eastern coast, the Florida Everglades and palmetto prairie, the tule marshes in central California, and the wet grasslands on the floodplains in the intermountain plateaus (number 41, fig. 5). Cordgrass, saltgrass and a few forbs form the coastal grassland ecosystem. Scattered shrubs and low to medium tall trees form the overstory with an understory of wiregrass and saw-palmetto in the palmetto grassland, or sawgrass and three-awn in the Everglades. Tules, other bulrushes, and sedges dominate the landscape in the wet marshes in the intermountain floodplains. Fauna in wet grasslands are as diverse as the grasslands. The Central Valley of California and the coastal marshes of Texas and Louisiana are important habitat for seasonal migrations of waterfowl, including the whooping crane. Klopatek and others (1979) estimated that by 1974 tule marshes had lost 89% of their original area, the Everglades had been reduced 57%, and the palmetto prairie had been reduced 27%. Losses were primarily to agriculture.

Annual grasslands.—Introduced annual grasses dominate the vegetation, although forbs and perennial bunchgrasses can also be found. Fauna includes mule deer, California quail, and numerous small mammals. The mourning dove is also an important species here (Verner and Boss 1980). Much of this type at lower elevations has been converted to irrigated agricultural land (number 42, fig. 5). At higher elevations, use is mainly livestock grazing, some dry farming, and intensive recreational use in proximity to large metropolitan areas in California (California Department of Forestry 1987).

Alpine.—This type occurs above timberline in the Rocky Mountain and Pacific Coast Sections (number 44, fig. 5). Grasses, grasslike species, and forbs predominate. The particular composition reflects the environment of the site which can vary dramatically depending upon wind and water stress, from wind swept, highly erosive, dry slopes to wet meadows. Lakes and ponds with endemic trout can be found within the type, although many lakes have been stocked with introduced species. Year-round mammals include the pika, pocket gopher, and the yellow-bellied marmot. An important game bird is the ptarmigan. Mule deer, elk, and mountain sheep use the ecosystem for summer forage. Traditionally, large bands of domestic sheep have grazed this ecosystem in summer. This practice has diminished, however, consistent with the decline in per capita consumption of lamb and mutton. Recreational use consists of hiking, hunting, and fishing during the summer, and skiing during the winter (Thilenius 1975).

OWNERSHIP

Most of the Nation's forest and rangelands are in nonfederal ownership. In 1987, about 1 billion acres, 67% of the total were owned by nonfederal public agencies, forest industry, farmers and ranchers, and other private individuals (table 3). Federal lands are administered primarily by two agencies: the Forest Service, responsible for 182 million acres of National Forest System lands; and the Bureau of Land Management, responsible for 176 million acres of National Resource Lands. The remaining federal lands are administered primarily by the National Park Service, the Fish and Wildlife Service in the Department of Interior, and the Department of Defense.

The nonfederal forest lands are concentrated in the East, and private rangelands are concentrated in the West (table 3 and fig. 6). In the North and Great Plains there are 78 million acres of rangeland, most of which is in

Table 3.—Ownership of forest and rangeland areas (thousand acres) in the United States by section and region, 1987

Section and region	Total forest and rangeland					Forest land[1]					Rangeland				
		Federal lands administered by					Federal lands administered by					Federal lands administered by			
	Total	Forest Service	Bureau of Land Mgt.	Other Federal	Non-Federal[2]	Total	Forest Service	Bureau of Land Mgt.	Other Federal	Non-Federal	Total	Forest Service	Bureau of Land Mgt.	Other Federal	Non-Federal
North															
Northeast	85,269	2,499	—	755	82,015	85,253	2,499	—	755	81,999	16	—	—	—	16
North Central	80,630	8,578	88	1,201	70,763	80,220	8,513	88	1,094	70,525	410	65	—	107	238
Total	165,899	11,077	88	1,956	152,778	165,473	11,012	88	1,849	152,524	426	65	—	107	254
South															
Southeast	92,133	5,266	—	4,140	82,727	87,744	5,266	—	3,943	78,535	4,389	—	—	197	4,192
South Central	227,106	7,189	11	2,733	217,173	115,741	7,189	11	2,734	105,808	111,365	—	—	—	111,365
Total	319,239	12,455	11	6,873	299,990	203,485	12,455	11	6,676	184,343	115,754	—	—	197	115,557
Rocky Mountains and Great Plains															
Rocky Mountains	473,922	95,539	142,490	23,851	212,042	138,104	68,306	19,196	6,967	43,635	335,818	27,233	123,294	16,884	168,407
Great Plains	81,807	3,560	323	717	77,207	4,227	1,008	—	92	3,127	77,580	2,552	323	625	74,080
Total	555,729	99,099	142,813	24,568	289,249	142,331	69,314	19,196	7,059	46,762	413,398	29,785	123,617	17,509	242,487
Pacific Coast															
Pacific Northwest	381,244	36,363	22,765	89,751	232,365	178,956	31,413	5,524	26,553	115,466	202,288	4,950	17,241	63,198	116,899
Pacific Southwest	79,616	23,429	10,129	7,401	38,657	41,129	17,566	2,172	1,482	19,909	38,487	5,863	7,957	5,919	18,748
Total	460,860	59,792	32,894	97,152	271,022	220,085	48,979	7,696	28,035	135,375	240,775	10,813	25,198	69,117	135,647
United States Total	1,501,727	182,423	175,806	130,549	1,012,949	731,374	141,760	26,991	43,619	519,004	770,353	40,663	148,815	86,930	493,945

[1] *See footnote 1, table 1.*

[2] *Data reported in this table might differ from data reported in summary assessment document. Rangeland area data for the summary document have been reconciled with the Soil Conservation Service Forest land area reported in this table has not been reconciled.*

Note. Data may not add to totals because of rounding

Source Forest Service RPA data base, 1987 and Soil Conservation Service reconciled figures, 1982.

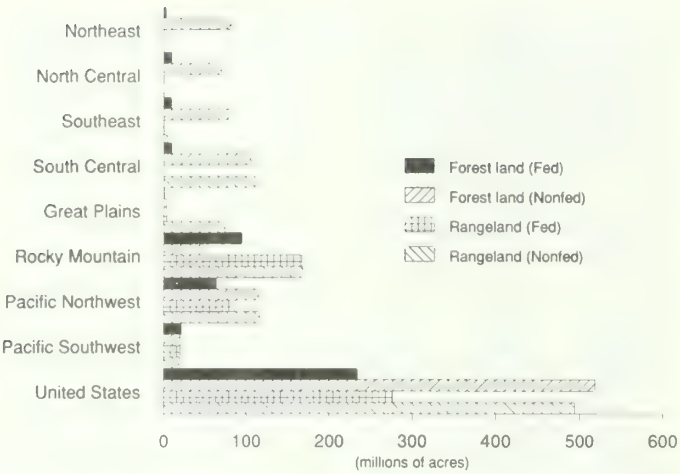


Figure 6.—Ownership of forest and rangeland by geographic region, 1987.

the Great Plains. Ninety-five percent of this rangeland is in nonfederal ownership. Nearly 156 million acres, or 92% of the forest land total in these 2 sections, is under nonfederal ownership. In the two southern regions, over 99.8% of the 116 million acres of rangeland is in nonfederal ownership and is located in Texas, Oklahoma, and Florida. Ninety percent of the 200 million acre total of forest land is in nonfederal ownership.

The three western regions, which include Alaska and Hawaii, have a forest and rangeland base of 935 million acres. About 38% is forested. The ownership of the western forests (358 million acres) is evenly divided between the federal government and other public and private owners, as is ownership of the 577 million acres of western rangelands.

The Rocky Mountain Section accounts for the largest area of rangeland in the United States (44% of the total), under both federal and nonfederal ownerships. The Section also accounts for a greater amount of federal forest land acres than any other Section. The largest area of nonfederal forest land is located in the South.

FOREST LAND PRODUCTIVITY

For this assessment, productivity of forest land is defined as the amount of wood per acre per year that can be produced in fully stocked natural stands. The natural potential has been used because measures of the potential are available for most regions of the United States, and it provides a uniform means of describing productivity of forests.

While no single measurement adequately describes the productivity of forest land for uses other than timber, an estimate of biological productivity is sometimes useful in helping to determine the forest's relative capacity for other uses. Chief among the factors that influence productivity for timber are soil, climate, and topography.

Major forest ecosystems will probably not be cleared for herbage and browse production, even though their potential productivity for forage is high. Such forest land types as the open-grown pine lands in the western United States currently produce considerable forage for domestic livestock and herbage and browse for deer and other wildlife. Under proper management, these types could probably produce increased quantities of forage; however, such management might lead to a reduction in the level of timber production.

Most of the Nation's high productivity forest lands are located west of the Cascade Mountains in the Pacific Northwest Region and in the South Central Region. Nearly 16 million forest land acres in the Pacific Northwest Region and about 21 million acres in the South Central Region have the potential for producing wood at a rate exceeding 120 cubic feet per acre per year in natural timber stands (table 4). The Pacific Northwest Region has the greatest area of low productivity lands; mainly because interior Alaska is included in the Region. Some 105 million acres, which represent 87% of Alaska's unreserved forest land total, has the potential of producing less than 20 cubic feet per acre per year. The Rocky Mountain Region also has large areas of low productivity forest. Over half of the forest land has the potential for producing less than 20 cubic feet per acre per year, and over three quarters of it can produce less than 50 cubic feet.

In the West, 77% of the redwood ecosystem of 1.3 million acres is highly productive (table 5). However, the largest areas in the 120+ cubic feet class are in the coastal Douglas-fir and hemlock-Sitka spruce types. High elevation fir-spruce, western hardwood, and arid land pinyon-juniper ecosystems are low in potential productivity. Fifty million acres of pinyon-juniper in the western interior and 68 million acres of fir-spruce make up nearly three-fifths of all of the forest land whose potential productivity is less than 20 cubic feet per acre per year. High elevation fir-spruce accounts for 34% of all forest lands in the lowest productivity class.

In the East, highly productive sites are found in the loblolly-shortleaf pine and oak-gum-cypress ecosystems of the lower Mississippi drainage and Atlantic coastal plain. Although no individual type can be identified with low-productivity sites, high-elevation fir-spruce accounts for 27% of the total forest land whose potential productivity is rated at less than 20 cubic feet per acre per year.

RANGELAND CONDITION

The term range condition has traditionally been used as a measure of the health of the range ecosystem. The Forest Service, SCS and BLM use different measures of range condition to inventory the Nation's rangelands. The Soil Conservation Service (SCS) inventories nonfederal rangelands and defines range condition as "...The present state of vegetation of a range site in relation to the climax (natural potential) plant community for that site. It is an expression of the relative degree to which the kinds, proportions, and amounts of plants in a plant community resemble that of the climax plant

Table 4.—Forest land area (million acres) in the United States, by timber productivity class, section and region, 1987

Section and region	Total	Productivity class[1] 120 + cu.ft.	85-120 cu.ft.	50-85 cu.ft.	20-50 cu.ft.	0-20 cu.ft.
North						
Northeast	85.3	3.5	15.3	37.3	26.5	2.7
North Central	80.2	3.5	15.0	29.3	29.5	2.9
Total	165.5	7.0	30.3	66.6	56.0	5.6
South						
Southeast	87.7	3.5	21.4	49.4	12.3	1.1
South Central	115.7	21.2	37.6	38.7	13.5	4.7
Total	203.4	24.7	59.0	88.1	25.8	5.8
Rocky Mountains and Great Plains						
Rocky Mountains	138.1	3.4	9.3	20.9	31.9	72.6
Great Plains	4.2	—	.3	1.0	2.3	.6
Total	142.3	3.4	9.6	21.9	34.2	73.2
Pacific Coast						
Pacific Northwest	179.0	15.9	11.3	12.3	19.3	120.2
Pacific Southwest	41.1	6.3	4.5	5.7	3.4	21.2
Total	220.1	22.2	15.8	18.0	22.7	141.4
United States Total	731.4	57.3	114.7	194.6	138.7	226.1

[1]*A measure of the mean annual growth obtainable in cubic feet per acre in fully stocked natural stands.*
Source: Forest Service RPA data base, 1987.

Table 5.—Forest land area (million acres) in the United States, by timber productivity class and ecosystem, 1987

Ecosystem	Total	Productivity class[1] 120 + cu.ft.	85-120 cu.ft.	50-85 cu.ft.	20-50 cu.ft.	0-20 cu.ft.	Reserved forest land
Forest land							
Eastern forest							
White-red-jack pine	14.5	1.3	2.5	5.5	4.5	0.2	0.5
Fir-spruce	19.6	.5	2.3	6.8	7.2	2.1	.7
Longleaf-slash pine	15.8	.8	3.7	8.5	2.4	.1	.3
Loblolly-shortleaf pine	49.1	8.2	17.0	19.2	4.1	.1	.5
Oak-pine	31.6	4.6	9.3	13.0	4.3	.2	.2
Oak-hickory	125.0.4	7.4	27.2	52.0	30.5	5.4	2.5
Oak-gum-cypress	29.5	4.4	9.0	11.7	2.7	1.0	.7
Elm-ash-cottonwood	15.1	1.3	3.1	5.1	4.7	.6	0.3
Maple-beech-birch	47.9	2.0	8.2	19.4	13.6	1.1	3.6
Aspen-birch	18.6	0.3	4.6	8.4	4.2	.3	.8
Nonstocked	6.5	([2])	.3	2.0	3.1	1.0	.1
Total	373.2	30.8	87.2	151.6	81.3	12.1	10.2
Western forest							
Douglas-fir	41.1	9.0	7.5	9.1	6.7	2.8	6.0
Ponderosa pine	30.6	1.4	1.9	6.0	15.3	3.0	3.0
Western white pine	.3	.1	.2	([2])	([2])	([2])	([2])
Fir-spruce	103.5	2.6	4.1	10.3	9.9	68.2	8.4
Hemlock-Sitka spruce	19.1	4.0	4.0	1.8	1.2	5.5	2.6
Larch	2.7	.5	1.2	.8	.1	([2])	.1
Lodgepole pine	18.2	.2	1.2	3.5	6.6	2.7	4.0
Redwood	1.3	1.0	.1	([2])	—	([2])	.2
Other western softwoods	27.2	.1	.1	.2	0.4	22.0	4.4
Western hardwoods	48.9	3.9	1.7	2.6	7.6	29.4	3.7
Nonstocked	5.4	.5	.3	.5	1.1	2.5	.5
Total	289.3	23.3	22.3	34.8	48.9	136.1	32.9
Other forest							
Chaparral	8.1	—	—	—	—	7.3	.8
Pinyon-juniper	51.8	—	—	—	—	50.0	1.8
Total	59.9	—	—	—	—	57.3	2.6
United States total	731.4	54.1	109.5	186.4	130.2	205.5	45.7

[1]*A measure of the mean annual growth obtainable in cubic feet per acre in fully stocked natural stands.*
[2]*Less than 100,000 acres.*
Source: Forest Service RPA data base, 1987.

Table 6.—Condition[1] of nonfederal rangeland area (thousand acres) by section and state, 1982

Section and state	Total	Condition Class: Excellent	Good	Fair	Poor	Other
North						
Minnesota	198.5	20.4	47.8	100.3	27.6	2.4
Missouri	217.8	1.3	56.2	99.7	55.6	5.0
Total	416.3	21.7	104.0	200.0	83.2	7.4
South						
Arkansas	164.6	4.9	21.5	70.2	68.0	0.0
Florida	3,803.9	24.5	272.5	1,831.4	1,640.1	35.4
Louisiana	241.3	12.5	148.5	54.0	26.3	0.0
Oklahoma	15,059.6	906.8	3,601.6	7,638.6	2,903.9	8.7
Texas	95,353.0	479.9	13,546.3	53,542.8	25,680.5	2,103.5
Total	114,622.4	1,428.6	17,590.4	63,137.0	30,318.8	2,147.6
Rocky Mountains and Great Plains						
Arizona	30,948.2	517.7	4,923.6	16,574.1	8,831.9	100.9
Colorado	24,222.5	333.2	5,802.6	14,012.2	4,033.2	41.3
Idaho	6,732.9	322.6	2,187.3	2,565.9	1,255.3	401.8
Kansas	16,908.9	965.5	8,091.9	6,121.9	1,666.2	63.4
Montana	37,837.0	5,027.5	17,272.1	12,605.1	2,747.2	185.1
Nebraska	23,095.7	2,188.5	12,636.1	7,110.2	1,069.0	91.9
Nevada	7,907.8	239.2	2,674.4	4,027.0	658.8	308.4
New Mexico	40,981.9	658.7	12,262.5	22,617.4	5,421.5	21.8
North Dakota	10,908.4	1,524.2	6,295.3	2,760.7	328.2	0.0
South Dakota	22,783.6	1,876.7	13,715.9	6,486.0	704.0	1.0
Utah	8,489.3	154.9	1,724.5	4,027.0	2,451.3	131.6
Wyoming	26,915.1	331.0	11,609.6	13,988.1	976.4	10.0
Total	257,731.3	14,139.7	99,195.8	112,895.6	30,143.0	1,357.2
Pacific Coast						
California	18,124.6	29.3	472.9	613.2	434.0	16,575.2
Oregon	9,392.0	226.4	1,813.2	3,485.5	3,731.1	135.8
Washington	5,637.0	629.0	1,168.5	1,816.1	1,933.0	0.4
Total	33,153.6	884.7	3,454.6	5,914.8	6,098.1	16,801.4
United States Total	405,913.6	16,474.7	120,344.8	182,097.4	66,683.1	20,313.6

[1]*SCS defines range condition as: ". . . .the present state of vegetation of a range site in relation to the climax (natural potential) plant community for that site. It is an expression of the relative degree to which the kinds, proportions, and amounts of plants in a plant community resemble that of the climax plant community for the site."*

Source: Table 41a.—Pasture land condition in 1982 by land compatibility subclass. Basic Statistics, 1982 National Resources Inventory, Soil Conservation Service, Iowa State University Statistical Laboratory, Statistical Bulletin No. 756, p. 64.

community for the site" (USDA Soil Conservation Service 1987). Montana leads all other states in area of nonfederal rangeland in the excellent condition class according to SCS estimates with 5.0 million acres (table 6). Nebraska is next (2.2 million acres), followed by South Dakota (1.9 million acres). States in the arid West contain the largest areas of rangeland in the poor condition class: Texas (25.7 million), Arizona (8.8 million) and New Mexico (5.4 million).

The Bureau of Land Management and the Forest Service have adopted separate ratings for ecological status and resource value rating. Both agencies are in a transition stage in inventory, monitoring and reporting. The Bureau of Land Management used data from a combination of ecological site inventory, soil vegetation inventory method and professional judgement. Rangeland administered by the Bureau of Land Management (BLM) with the greatest area in the excellent condition class is found in Nevada (2.8 million acres), followed by Utah (1.0 million) and Wyoming (0.8 million) (table 7). Arizona, with 26.0 million acres, leads BLM rangeland in the poor condition class, followed by Nevada (10.8 million) and New Mexico (3.0 million).

The Forest Service reported rangeland condition in 1987 in terms of ecological status and satisfactory livestock forage conditions. Seventy-nine percent of the rangeland on the national forests is classed as satisfactory, and 21% is classed as unsatisfactory (table 8).

WATER AREAS

About 5% of the total area of the United States is water (table 1). This water area includes ponds, lakes, and reservoirs that are at least 2 acres in size and streams and waterways that are at least 120 feet wide. It also includes

Table 7.—Condition of BLM rangeland area (thousand acres) by section and state, 1986

Section and state	Condition Class					
	Total	Excellent	Good	Fair	Poor	Other
Rocky Mountains						
Arizona	36,006	427	3,006	6,587	25,986	—
Colorado	7,197	222	1,179	3,089	1,992	715
Idaho	12,108	415	2,730	3,724	2,717	2,522
Montana	8,221	397	4,924	1,886	109	905
Nevada	45,121	2,759	12,059	18,372	10,819	1,112
New Mexico	12,889	57	3,131	6,142	2,977	582
Utah	20,845	965	6,895	9,023	297	3,665
Wyoming	17,668	836	8,035	6,414	1,097	1,286
Total	160,055	6,078	41,959	55,237	45,994	10,787
Pacific Coast						
California	9,179	69	4,011	3,992	952	155
Oregon	13,922	537	3,528	7,027	2,363	467
Total	23,101	606	7,539	11,019	3,315	622
All Sections Total	183,156	6,684	49,498	66,256	49,309	11,409

Source: Combination of ecological site inventories, soil vegetation inventories, and professional judgment.

coastal waterways, major coastal bays and harbors, except those in Alaska and Hawaii, and the Great Lakes.

Of the 108 million acres of water, 51 million acres is in large lakes and streams that are 40 acres or larger (but not the Great Lakes). Fifty-four percent of these large lakes and streams (27 million acres) are located in the eastern half of the country. Within the East, the large water areas are concentrated in the northernmost tier of states, where glaciation formed numerous lake basins; and in the southernmost tier of states, where part of the low-lying land along the coasts and major rivers is covered with water. The remaining 24 million acres in the western states are contained in manmade reservoirs and impoundments constructed to store water for irrigation, electric power generation, and flood control.

The area of small inland water, which includes streams that are less than one-eighth mile in width and lakes and ponds between 2 and 40 acres in size, amounts to 9.9 million acres. Many of these small water areas are manmade, largely the product of federal and state programs concerned with watershed protection, flood control, or wildlife value enhancement. The geographic distribution of these small water areas is similar to that of the large water areas, generally tied to landform and rainfall.

About 36 million of the 46 million acres of coastal waterways, harbors, and bays are the in Great Lakes. The largest bays include Chesapeake, Delaware, and San Francisco; large harbors include New York; largest sounds include Long Island and Puget; and largest straits include Juan de Fuca and Georgia. These and the other coastal water bodies along the Atlantic, Gulf, and Pacific Coasts are included in the total water figure for the United States. These navigable waters are considered to be publicly owned and, therefore, are regulated by federal and state laws. In many cases, however, public access is controlled by the owners of the adjoining lands.

ENVIRONMENTAL HEALTH

Atmospheric Deposition

The forests, grasslands, and croplands of the United States supported a population of 1-2 million native Americans when European colonization began in the 16th and 17th centuries. Today, the U.S. land base supports the food, fiber, outdoor recreation, and environmental needs of about 240 million people. Additionally, the U.S. in the last decade exported 40% of the value of its cropland, 5% of its livestock production, and 17% of the industrial wood harvest (Council on Environmental Quality 1985). Increasingly, the land base must not only support more people but also accept the wastes and byproducts of our industrialized society.

During the last 5-10 years, concerns have increased about the possible effects of airborne pollution on forests. Interest has been generated, in part, by the importance and continued concern about acidic precipitation ("acid rain") and forest declines. The current, severe forest deterioration in central Europe has also aroused concern for North American forests. At this time there are still insufficient data to conclude that these recent changes in forest condition constitute a new type of forest decline in the United States.

Sources and Types

Atmospheric deposition or "acid rain" is not a new phenomenon. A study of the chemistry of precipitation around the town of Manchester completed in 1852 by an English chemist named Robert Smith was one of the first reports of strong acid occurrence in precipitation. Primary pollutants, directly emitted into the atmosphere as gases, include sulfur dioxide (SO_2), nitrogen oxides

Table 8.—Condition of national forest rangeland suitable acres[1] (thousand acres) by section and state, 1987

Section and state	Total		Potential natural communities		Late serial		Mid-serial		Early Serial		Annual grasslands	
	Satis-factory	Unsatis-factory	Satis-factory	Unsatis-factory	Satis-factory	Unsatis-factory	Satis-factory	Unsatis-factory	Satis-factory	Unsatis-factory	Satis-factory	Unsatis-factory
South												
Alabama	56	—	([2])	—	37	—	3	—	16	—	—	—
Arkansas	691	38	214	11	337	18	120	7	20	2	—	—
Florida	133	—	8	—	101	—	24	—	—	—	—	—
Georgia	63	42	—	—	62	41	—	—	1	1	—	—
Kentucky	4	—	—	—	([2])	—	—	—	([2])	—	—	—
Louisiana	188	—	—	—	179	—	—	—	9	—	—	—
Mississippi	69	37	—	—	5	19	59	18	5	—	—	—
Oklahoma	242	11	77	4	133	5	28	1	4	1	—	—
Texas	631	4	190	—	91	—	103	—	247	4	—	—
Virginia	7	—	—	—	3	—	2	—	2	—	—	—
Total	2,080	132	489	15	948	83	339	26	304	8	—	—
Rocky Mountains and Great Plains												
Arizona	6,286	2,437	1,526	40	2,863	367	1,654	1,336	243	694	—	—
Colorado	4,297	614	162	13	984	59	2,594	261	557	281	—	—
Idaho	3,901	935	748	11	1,886	23	1,045	604	222	297	—	—
Kansas	34	71	—	—	8	—	26	33	—	38	—	—
Montana	2,287	222	804	93	835	65	455	44	193	20	—	—
Nebraska	295	41	6	—	34	—	209	31	46	10	—	—
Nevada	1,280	1,025	218	([2])	516	([2])	503	323	43	702	—	—
New Mexico	4,279	1,523	926	44	1,407	205	1,719	982	227	292	—	—
North Dakota	910	19	414	9	356	7	123	3	17	([2])	—	—
South Dakota	1,001	295	75	1	536	2	381	159	9	133	—	—
Utah	2,347	914	231	—	1,036	—	1,002	474	78	440	—	—
Wyoming	2,268	441	359	25	1,000	27	893	216	16	173	—	—
Total	29,185	8,537	5,469	236	11,461	755	10,604	4,466	1,651	3,080	—	—
Pacific Coast												
California	3,646	876	520	18	768	62	1,248	398	723	380	387	18
Oregon	4,885	863	683	45	1,776	154	1,814	350	612	314	—	—
Washington	926	170	78	10	135	24	366	52	347	84	—	—
Total	9,457	1,909	1,281	73	2,679	240	3,428	800	1,682	778	387	18
United States total	40,722	10,578	7,239	324	15,088	1,078	14,371	5,292	3,637	3,866	387	18

[1]The following terms are defined in USDA-Forest Service manual 2200:

Ecological Status—the degree of similarity between the present community and the potential natural community of a site. Ecological status considers only secondary succession.

Suitable acres—Acres within grazing allotments considered suitable for livestock grazing, i.e., that is accessible or that can become accessible to livestock, sustained-yield basis under reasonable management goals. Both rangelands and forested ranges are included in this table. There is overlap in acres in this table and acres described as forest land elsewhere in this chapter.

Satisfactory livestock forage condition—the soil is adequately protected and the forage species composition and production are at acceptable levels or the trend in forage species composition and production is acceptable.

[2]Less than 500 acres.

Source: U.S. Department of Agriculture, Forest Service, 1987. (Unpublished data), Range Management Staff, Washington DC.

(NO_x), toxic trace metals, and volatile organic hydrocarbons (VOCs). Secondary pollutants are formed in the atmosphere during chemical reactions involving the primary pollutants. The most common of these are the acidic compounds formed when sulfur or nitrogen oxides combine with oxygen to form acidic gases or particles (dry deposition) or then combine with moisture to form acidic rain, snow, hail, sleet or fog (wet deposition) (fig. 7). Another secondary pollutant, ozone, is produced when sunlight triggers reactions involving NO_x, oxygen, and VOCs. Ozone is very toxic to both humans and plants.

The burning of fossil fuels (coal, oil, natural gas) produces most of these pollutants. Natural sources of NO_x and SO_2 provide 13% and 6%, respectively, of the annual emissions of these compounds, and include emissions from soils, oceans, agricultural crops, and natural vegetation (trees, shrubs, grasses) (Barchet 1987).

U.S. Distribution

A high-quality weekly wet deposition network, the National Atmospheric Deposition Program's National

Primary Pollutants		Secondary Pollutants
SO_2	H_2O_2 and O_3 (in clouds) $OH + O_2$ (in air) Oxidants (wet surfaces) →	H_2SO_4
NO_x	Sunlight --> OH (in air) →	HNO_3
NO_x + VOC	Sunlight (in air) →	O_3
VOC	Sunlight --> HO_2 (in air) →	H_2O_2

Source: NAPAP, 1987

Figure 7.—Acid rain—precursors and products.

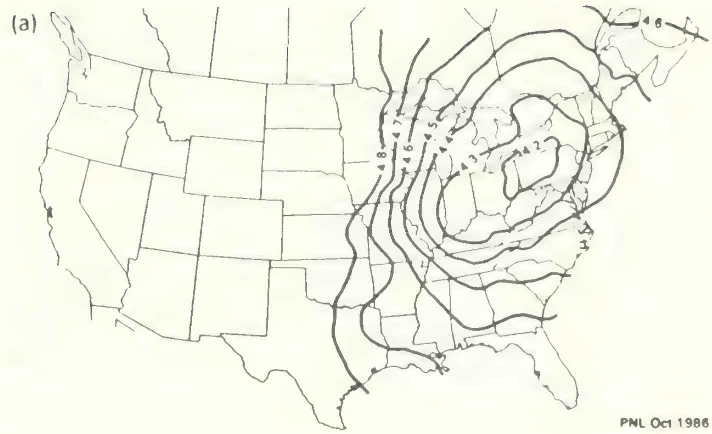
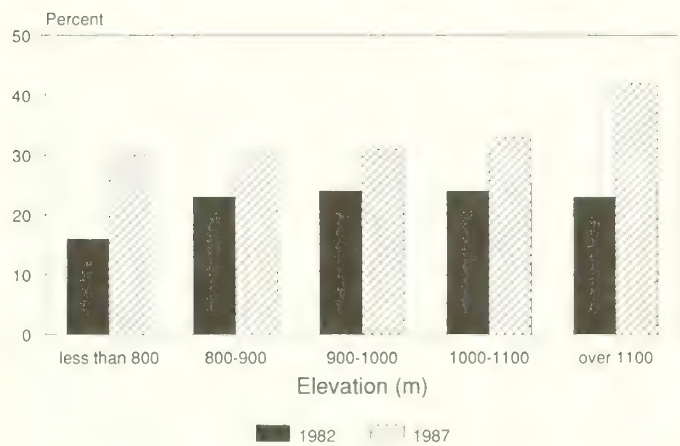


Figure 8.—The 1980-1984 annual composite distribution of (a) precipitation-weighted pH.



SOURCE: FS/EPA Forest Response Program

Figure 9.—Percent standing dead spruce in northeastern United States selected survey plots, 1982-1987.

Trends Network (NADP NTN), has been established across the United States. The Forest Service cooperates in this effort by supporting data collection at 11 sites on national forest land. The NADP NTN data, integrated with data from other wet deposition networks, provide a picture of the geographical distribution of the precipitation chemistry and wet deposition of a range of chemical species across the contiguous 48 states (fig. 8).

The area of highest acidity in rainfall for 1980-1985 is centered in western Pennsylvania, eastern Ohio, and Southwestern New York. Except for the West Coast, from Washington to California, where much of the annual precipitation falls as winter rains, wet deposition of most pollutants is higher in summer than in winter. The natural background (pre-1500 A.D.) pH of rain in the eastern U.S. may have been as low as 5.0. This is based on estimates of background concentrations of gaseous pollutants and on wet deposition measurements at remote areas of the earth today. In the semi-arid West, alkaline dusts raised by the wind could have neutralized some of the acidity and produced rain with slightly higher background pH (between 5.3 and 6.0) (Barchet 1987).

Forest Declines

Declines from many causes (both known and unknown) have occurred periodically in tree species in the United States during the last 100-200 years. But in the last 10-20 years, forest condition changes have occurred in several forest regions that may be different from changes observed previously. Death rates of high elevation red spruce along the Appalachian Mountain chain in the northeastern U.S. appear to have increased (fig. 9), and numbers of standing dead spruce are higher than expected. This is not the case with northeastern, low elevation red spruce and southeastern, high elevation red spruce. Radial increment growth decreases (starting about 1960) have been documented at high and low elevations. These growth reductions have been consistent, abrupt, and unreversed. Death rates and growth of northern, high-elevation fir forests are unchanged. Growth decreases have occurred (since 1970) for northern, low-elevation balsam fir.

Radial growth decreases have also been reported in natural stands of commerically important conifer species (loblolly pine, slash pine) in the Southeast and shortleaf pine in the East at low elevations, with no visible foliar symptoms. Visible foliar damage and growth decreases have been documented for eastern white pine, and for ponderosa pine, Jeffrey pine, white fir, limber pine, incense cedar, and California black oak in southern and central California. Sugar maple decline has recently been reported in the northeastern U.S. and southeastern

Canadian provinces; the most severe damage occurs in stands managed for maple syrup production. Symptoms include branch and top dieback, decrease in sap production, and increased mortality. For most of these recent forest condition changes, the cause is still unknown.

Airborne pollutants are among the suspected causes of death in high elevation spruce, of spruce growth decreases, and of eastern and southeastern pine growth decreases. Recent results of atmospheric monitoring show that high-elevation forests are being exposed to greater pollutant concentrations and/or deposition than low-elevation forests in the East. Other recent results from dendrochronology (tree-ring) studies indicate that natural forest stand aging may account for the radial growth declines observed in low elevation spruce and fir forests. Damage to southern Fraser fir forests is being caused by the balsam woolly adelgid. Acidic deposition and management intensity are speculated factors in the apparent sugar maple decline in North America. A cooperative U.S.-Canadian study is investigating this decline.

The airborne pollutant ozone has been shown to cause visible foliar injury, decreased growth, and change in the species composition of some forests in southern California. Death of trees weakened by ozone is usually caused by secondary agents such as bark beetles and root-rotting fungi. The foliar injury symptoms have been duplicated experimentally in controlled exposure tests with ozone. Ozone has also been shown to induce visible injury and decrease growth in eastern white pine.

In all cases, airborne pollutants cannot yet be ruled out as one of the stresses causing these forest condition changes. Indeed, it is possible that air pollution is at least involved in chronic decreases in tree vigor.

Forest Effects Research

A large forestry research effort, the USFS/EPA Forest Response Program, was begun in 1985 to investigate the above forest condition changes and to determine the cause or causes. Results of this effort are just starting to be reported. The Forest Response Program is specifically designed to provide information for regulatory decision-making under the Clean Air Act (EPA), as well as for resource management decision-making (FS). Research is ongoing to investigate possible effects in eastern spruce-fir forests, southern commercial pines, eastern hardwoods, and western conifers. Another part of this program involves the design and establishment of a forest condition monitoring system for the U.S. to detect changes in forest health and productivity.

This forestry research program will operate through 1991 as shown in table 9, with parts of the program continuing well into the 1990s. Many answers to the original research questions are expected by 1990.

Table 9.—Forest Service/EPA forest response program major outputs

Product	Completion Date
Evaluation of the Extent and Magnitude of Recent Changes in Forest Condition	12/88
Evaluation of the Role of Non-Air Pollution Factors in Growth Reduction and Visible Decline	12/88
Quantitative Estimates of Seedling Response to Sulfur, Nitrogen, and Associated Pollutants in Forest Damage	4/88, then 4/89 update
Evaluation of the Roles of Sulfur, Nitrogen, and Associated Pollutants in Forest Damage	9/89 4/91
Projection of Forest Response to Alternative Deposition Levels	12/91

CHAPTER 2: THE NORTH AND THE GREAT PLAINS

LOCATION AND CHARACTERISTICS

The Great Plains Section is included with the North Section in this chapter because the forest ecosystems found in the Great Plains are more closely aligned with those found in the North than with those in the Rocky Mountains. The tables in the previous section group the Great Plains Section with the Rocky Mountains Section; however, in order to facilitate comparison with similar tables published during the last national Assessment, dated 1977 (USDA Forest Service 1981). The Great Plains Section is composed of 4 States (Kansas, Nebraska, North Dakota, and South Dakota). In this Chapter, the term "the area" will be used to describe the joint North and Great Plains Sections.

The North Section includes 20 states in the northeastern and north central parts of the United States (fig. 2). The North is further divided into two regions—Northeast and North Central. The area stretches from the Atlantic seaboard in the east to the prairies in the west; from the Ohio river, the Appalachian highlands, and the Northern Piedmont in the south to the Canadian border and the Great Lakes in the north. The more northern states of the area have moderately long, relatively severe winters. Annual precipitation is moderate and ranges from 25 to 45 inches; often half of this precipitation comes as snow. Short growing seasons of 100-140 frost-free days place limits on agricultural production. Much of this area has been glaciated and glacial landforms are common. The soils are generally well suited for forests. Most soils are acid and strongly leached, with an upper layer of organic matter. Soils with high water tables are common in many areas.

The states in the southern half of the area have cold winters and warm summers. Precipitation is greater than in the northern half and ranges from 35 to 60 inches. Most of the precipitation comes in the summer months. Growing seasons of 120-200 frost-free days and favorable soils produce some of the Nation's most productive agricultural lands. Most of the area is rolling or nearly flat, but the Appalachian mountains in the east (reaching from West Virginia to Maine) have steep slopes and elevations up to 3,000 feet. Many of the soils are low in bases and have subsurface horizons of clay accumulation. Soils are usually moist but during the summer are dry part of the time.

FOREST LAND

Ecosystems

The 607 million acres of land in the North and Great Plains include 169.7 million acres of forest land (table 1), 28% of the total, of which 162.8 million acres are unreserved. Ninety-three percent of the forest land (158.2 million acres) is timberland, and 4% (6.7 million acres) is reserved timberland. Much of this forest land, especially in the Northeast Region, lies close to densely populated areas and receives intensive pressure from a wide array of forest users. Controversy sometimes flares as land managers and land users disagree over the future of these closely-watched forests.

Because most of the North Section, except for the prairie fringe in the western portions of Minnesota, Iowa, and Missouri, was originally forested, these lands tend to revert back to forests if disturbed, then allowed to stand idle. In the Northeast Region this process has occurred for several decades, and forest area has increased because of abandoned cropland and pasture returning to forest. In the North Central Region gains in forest area have been noticed more recently, and result largely from land formerly classed as wooded pasture no longer being grazed because of intensified feeding of cattle in feedlots.

Oak-hickory.—This ecosystem is the largest in the area with 47.8 million acres of unreserved forest land or 29% of the total (table 10). Generally, the oak-hickory ecosystem grows in a wide band along the southern portion of the area and joins the maple-beech-birch ecosystem to the north (figs. 5 and 10). The ecosystem may be broken down into smaller associations to reflect the species mix. Hickories are a small but consistent component. Stands closer to the maple-beech-birch transition line tend to be stocked more heavily with species other than oaks and hickories, such as ash, basswood, sugar maple and elm.

Benefits of oak-hickory forests range from providing habitat for squirrels, wild turkeys and other mast-eaters, to providing durable, beautifully-grained lumber for furniture, cabinets and flooring. High quality white oak is especially prized in European markets. Management of oak-hickory stands is impeded by the difficulty of regenerating oaks, and the continuing problem of a scarcity of markets for less desirable hardwoods which comprise a sizeable part of many stands.

Maple-beech-birch.—This ecosystem is the second largest in the area with 43.4 million acres, 27% of the unreserved forest. The area of this ecosystem is generally increasing because the major species are long-lived and shade-tolerant. If present in sufficient numbers in the understory of other ecosystems that are disturbed, these species may take over the site. Sugar maple, yellow birch, and basswood are important components of the ecosystem and are valuable as forest products. Red maple is less valuable but is fast-growing and aggressive. It is rapidly expanding its role in the ecosystem, particularly in the Northeast.

Table 10.—Area of unreserved forest land (thousand acres) in the North and Great Plains Sections by region and forest ecosystem, 1987

Forest ecosystem	Total North and Great Plains	North Section			Great Plains Section
		Total	Northeast Region	North Central Region	
Oak-hickory	47,783	47,073	23,927	23,146	710
Maple-beech-birch	43,395	43,247	26,836	16,411	148
Spruce-fir	18,857	18,840	10,262	8,578	17
Aspen-birch	17,938	17,754	3,174	14,580	184
White-red-jack pine	13,483	11,966	7,917	4,049	1,517
Elm-ash-cottonwood	11,856	10,546	3,784	6,762	1,310
Oak-pine	3,672	3,555	2,640	915	117
Loblolly-shortleaf pine	2,400	2,398	1,725	673	2
Oak-gum-cypress	797	797	363	434	—
Other	32	—	—	—	32
Nonstocked	2,571	2,449	636	1,813	122
All ecosystems	162,784	158,625	81,264	77,361	4,159

Figure 10.—An oak-hickory sawtimber stand.

The wide diversity of tree, shrub and forb species in maple-beech-birch stands make this ecosystem an important provider of a esthetic, wildlife, and recreational resources.

Spruce-fir.—Third in size in the area is the spruce-fir ecosystem with 18.9 million acres, 12% of the available forest. Spruce-fir stands are most dominant in Maine where they form large continuous blocks and comprise 43% of the North's spruce-fir total area. The remainder is generally in smaller pockets scattered throughout the northern reaches of the maple-beech-birch ecosystem in the Northeast and in the extreme north of the three Lake States (Minnesota, Wisconsin, and Michigan).

Spruce-fir stands provide many forest products, perhaps most importantly, pulpwood. The fact that this ecosystem is generally remote and removed from urban areas makes it a precious recreational resource.

Aspen-birch.—The aspen-birch ecosystem extends over 17.9 million acres of available forest in the North and Great Plains—the fourth largest area. Located primarily (81% of the area) in the northern portion of the three Lake States, there are also sizeable areas of aspen-birch in the northern tier of the Northeastern States. Aspen-birch is a pioneer ecosystem, reclothing the land after major disturbances such as fire or heavy logging. Trees are short-lived and stands often revert to another forest type unless they are clearcut, which assures the continuation of the type. The aspen-birch area has been in decline because most stands were not managed until development of technology using aspen to produce waferboard. Since then, more stands are being clearcut and area losses are probably being slowed. Aspen-birch stands provide excellent wildlife habitat, especially for ruffed grouse, deer, and moose.

White-red-jack pine.—This ecosystem ranks fifth in size in the area with 13.5 million acres. It occurs scattered throughout the northern tier of states—remnants of the vast pineries of the past that supported a softwood lumber industry responsible for much of the construction in the Northeast and Midwest during the late 1800s and early 1900s. In the eastern range of the ecosystem, white pine and hemlock are the most important components; but in the western range, red and jack pines predominate. The pines have traditionally been valued for forest products, from saw logs to pulpwood to poles. And pines, especially mature trees, are an essential ingredient in the enjoyment of the landscape by outdoor recreationists of all kinds. Much of the tree planting done in the North involves pines, chiefly red and white pines.

Elm-ash-cottonwood.—Stands in this ecosystem grow scattered widely on 11.9 million acres throughout the area. The ecosystem is generally found along moist river and stream bottoms, and in or around swamps, gullies, and small depressions of slow drainage. The large mix of species in this type assures that stand composition will change quickly. Dutch elm disease has reduced the amount of elm in stands, and other aggressive species, such as red maple, sometimes fill in behind it. Most of the species associated with the ecosystem are not highly valued for timber products except for the ash species, which are prized for tool handles and sports equipment. Elm-ash-cottonwood stands are highly valued for helping to prevent erosion on moist, vulnerable soils, for providing habitat for many game and nongame species, and for their bright colors in the fall.

Other ecosystems in the area include oak-pine (3.7 million acres), loblolly-shortleaf pine (2.4 million acres), and oak-gum-cypress (0.8 million acres). These ecosystems occur on the southern edge of the North Section, and are discussed in more detail in the next section. Nonstocked forest land accounts for the remaining 2.6 million acres.

Ownership

Although there is much variation among states, in 1987 about 80% of all timberland in the North and Great Plains was held by private individuals or firms (fig. 11). An estimated 3.3 million private owners hold 126 million acres of timberland. Federal, state and other public ownerships account for the remaining 20% of the timberland, over 32 million acres.

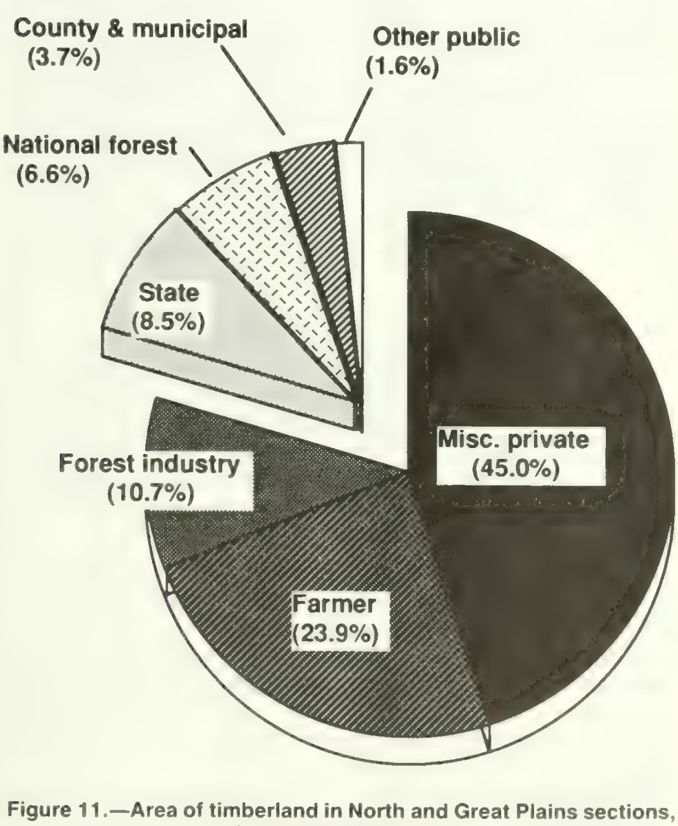


Figure 11.—Area of timberland in North and Great Plains sections, by ownership, 1987.

A profile of the private owners shows that 87% of them are represented by a single individual or a husband-and-wife team. These persons hold 67% of the private forest land. Six percent of the private owners are in some other kind of family partnership (involving other family members or family corporations), and they hold 9% of the private forest. Another 3.5% of the private owners consists of corporations (other than family corporations), accounting for 19% of the private forest.

The remaining 3.5% of private owners is a mix of nonfamily partnerships, noncorporate sport and recreation clubs, and undivided estates, and collectively accounts for 5% of the private forest area.

Within the single individual or husband-and-wife team owner group mentioned above, farmers own more forest land than any other owner. Farmers control nearly 18% of the private forest land, although they represent less than 4% of the private owners (these figures do not include land owned by farmers who are part-time or retired, whose land is included in the total farmer-owned lands in this report). Retired people own nearly 15% of the private forest and represent 20% of the forest landowners. White collar workers own 17% of the private forest land, although they account for the largest portion of private owners—36%. The remaining individual owners are blue collar workers, housewives, and other private owners, including service workers. This group holds 18% of the private forest land and represents 25% of the private owners.

Forest industries, comprising most of the corporate forest land, own 17.0 million acres in the North and Great Plains. Other corporations owning sizeable acreages of forest land include mining and drilling companies, insurance companies, real estate firms, railroads, corporate farms, public utilities, youth organizations, and sport and recreation clubs.

The more forest land an individual owns, the more likely he or she is to manage timber actively. Even in the heavily populated Northeast most owners of more than 500 acres of forest land intend to harvest timber from their land at some time in the future. Nearly one-third of the private forest land in the North is in ownerships greater than 500 acres, and about half of this is concentrated in the hands of owners who hold more than 10,000 acres of forest land. Most of these are forest-based industries or are groups that employ foresters and actively manage their forest lands. An additional 40% of the private forest land is in ownerships of 100 to 500 acres. Many of these ownerships could produce substantial amounts of timber on a continuing basis. The remaining 27% of the private forest land is in ownerships of fewer than 100 acres. These lands may not be the most important for timber production, but they may be very important for other forest values. Location, size, and owner objectives may effectively remove these lands from the timber-producing base.

Some 10.4 million acres of timberland are located in national forests in the area. This area is virtually

unchanged since 1977 despite increases in wilderness designations and areas deemed under custodial management as a result of the forest planning process. Federal lands other than national forests in the area amount to 1.5 million acres. State, county, municipal, and Indian forests are an additional 20.3 million acres. Many of these latter holdings are located in the Lake States and are lands that reverted to public ownership, through tax delinquency, during the depression years of the 1930s. In the Northeast, many of these lands are important watersheds for municipalities. They are also crucial for cold water fisheries and wildlife habitat.

Productivity

Sixty-two percent of the unreserved forest land in the area is capable of producing 50 cubic feet of wood or more per acre per year (fig. 12). The most productive land—land capable of producing over 120 cubic feet per acre annually—accounts for 4% of the total unreserved forest area. Highly productive land, capable of producing 85 to 120 cubic feet of wood annually on each acre, makes up 18% of the total. And moderately productive land, capable of producing 50 to 85 cubic feet per acre, represents 40%.

Forest land of marginal productive capacity, 20 to 50 cubic feet, accounts for 35% of the total. Unproductive forest land, incapable of producing 20 cubic feet per acre per year, occurs on 3% of the total.

Productivity is somewhat higher in the Northeast than in the North Central Region. Sixty-six percent of the Northeast's forest land (53.5 million acres) can produce in excess of 50 cubic feet, compared to 60% (46.1 million acres) in the North Central Region. Sites with poorer productive capability are often found in areas of poor drainage, such as the swamps and bogs supporting black spruce, northern white-cedar, and tamarack, located along the northern edge of the northern tier of states. Shallow soils and areas of hardpan in Missouri make this the state with the largest area of unreserved forest land incapable of producing annually more than 50 cubic feet per acre in the area (8.5 million acres or 69% of the total). Eastern redcedar, post oak-blackjack oak,black oak-scarlet oak, and white oak associations all occupy large areas of marginal or unproductive sites in Missouri. Substantial areas of dry, shallow soils produce sites with low productivity in the oak-hickory ecosystem in Pennsylvania and West Virginia, and in the maple-beech-birch ecosystem in Maine, Michigan, Vermont, New York, Wisconsin, New Hampshire, and Pennsylvania. Poorly drained soils contribute to the large area of sites with low productivity in the spruce-fir ecosystem in Minnesota, Maine, and Michigan.

Productivity is lowest in the Great Plains Section where only 29% of the unreserved forest land (1.2 million acres) can produce more than 50 cubic feet per acre annually.

A crude estimate of average potential productivity on unreserved forest land for the North and Great Plains combined is 58 cubic feet per acre per year. This estimate

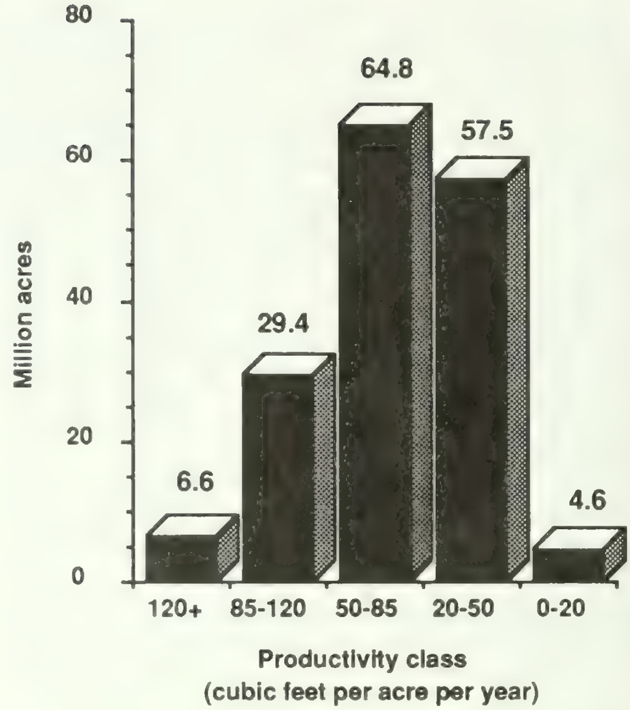


Figure 12.—Area of unreserved forest land in North and Great Plains sections, by productivity class, 1987.

is made by weighting the mid-point of each productivity class (excluding the 0 to 20 cubic feet class) by the number of acres in that class, then discounting the result by 10% to adjust for holes in the forest canopy caused by rocky outcrops, marshes, buildings, etc. that prevent yields over large areas from reaching predicted levels. This estimate compares with the average net annual growth per acre on timberland in 1986 for the area of 35 cubic feet. Actual productivity will approach the potential as stocking levels improve and as forest management is more widely practiced.

Use

Forest land in the North and Great Plains produces a wide range of timber products, from saw logs and pulpwood to posts and fuelwood. But timber products are just one of many uses of the forest. Recreation demand grows each year. Camping, hiking, fishing, cross-country skiing, bird watching, snowmobiling and hunting are some of the ways people in the area use forest land to renew themselves.

Many wildlife species exist in a forest habitat, and their needs must be considered in managing and using the land. A classic example is the Kirtland's warbler, an endangered song bird that nests only in seedling-sapling stands of jack pine in a limited area of the Northern Lower Peninsula of Michigan. Without a continual supply of these trees in the small geographic area required, the bird could become extinct.

Urban forests, are also becoming an increasingly important resource. This is especially true in the Northeast,

but it is generally true over much of the area. Urban forests are made up of several components including street trees, volunteer and planted exotic and native yard trees, islands of planted, residual or second-growth forests, and islands of pioneer tree communities on abandoned land (Rowntree 1987).

In the Northeast, some urban forests have the same characteristics as timberland, the only difference being their urban orientation. In past inventories urban forests have been classed as noncommercial forest land within urban areas that were surrounded by urban development (not parks). Some estimates of urban forests are now based on forest areas meeting timberland definition, but falling within Bureau of Census tracts with population densities of greater than 500 persons per square mile (urban areas). This new criterion resulted in a much larger estimate of urban forest area (Powell and Kingsley 1980).

In the North Central Region and Great Plains Section there are no reliable estimates of urban forest area. However, urban forests are a significant component of many metropolitan areas. They occur as county parks, forest preserves, nature areas, municipal watersheds, unused parcels of land, street trees, wooded river banks, powerline corridors and cemeteries.

The great diversity of the urban forest makes it difficult to generalize about the potential benefits of management, or limitations of management practices. It is probably safe to say that the greatest benefits from urban forests are from recreation, esthetics, and other improvements in the general quality of urban life. These improvements may take the form of physical effects on the environment (e.g. moderating temperature extremes), as well as improvements in psychological well-being. Studies have shown that trees have a calming effect on people, which results in measurable reductions in physiological stress (Ulrich 1981, 1984).

Political and economic factors make it unlikely that urban forests can contribute significantly to the region's production of timber. However, some trees will be harvested as urban forests are converted to home sites, shopping malls, parking lots, etc.

Trends in Forest Area

The area in timberland in New England and the Middle Atlantic states increased steadily from 1952 to 1987. Forest areas in wilderness, parks, and natural areas on national forest and state-owned land also increased during this same time period. Some land use changes are not permanent. The land cleared for crops today or many years ago can revert to forest cover in a short period of time if left uncultivated. Conversely, cropland put into a Christmas tree plantation or planted to trees can return to its previous use. Land cleared for mining and waste disposal can be restored to cropland, pasture, or forest use.

In the North Central Region and Great Plains Section, trends are mixed. Some states, such as Wisconsin, Illinois, Indiana, and Kansas, had shown steady declines in timberland area between 1952 and 1977. But between 1977 and 1987 they showed small increases in area, primarily due to the reversion of wooded pasture to timberland because of improved stocking levels on previously grazed land. Other states show a continual decline in area of timberland, and 50-year projections suggest declines for all states in these areas.

The forest is viewed by some as a residual land use. People in agriculture look for potential cropland needs to be supplied from the forest land base. To the home builder, tree cover can be a hindrance to site preparation prior to construction and trees can be a disposal problem. Other builders seek wooded acres to subdivide and to charge premium prices for wooded house lots.

The changing nature of agriculture in the Northeast has had the greatest effect on the area in forest land. Most of the increase in forest land can be directly linked to the decrease in farm area, particularly the dairy sector of the farm community. Many factors are responsible for the change—inflation, capital costs, nonfarm employment, comparatively poor soils, transportation costs. The area in pasture has continued to decline across the region, while cropland areas have leveled off or increased in many areas.

Future resource demands, economic considerations, and cultural and societal factors will influence future forest area changes. The demographic structure of the population and of the resource owners could produce dramatic changes. The most significant of these demographic changes are projected to be (1) the decline in population growth, (2) the general aging of the population and resource owners, and (3) the passage of the baby boom generation to retirement age. Economic considerations include the size and productivity of the forest holding. Forest holdings that are too small or support low value timber may not remain in the forest land base unless they are held for other reasons, such as recreation, wildlife, or watershed values. Cultural and societal factors such as public concern for environmental quality can decrease forest land conversions to agricultural land use. The pine lands legislation in New Jersey is a prime example. This act has almost stopped the loss of forest and agricultural land to urban uses. Another example is township-level harvesting regulations that have changed how land can be used.

Sorting out the implications of current changes in land use is no easy task. Urban areas have doubled in size. The area in farms has declined rapidly. Forests have gained in some areas while losing ground in others. Technological changes in the production, marketing, and utilization of forest and agricultural products and their substitutes will have major impacts. The strength of the American dollar relative to other world currencies, trade deficits, inflation,and other economic issues will come into play. The attitudes of farmers, forest-land owners, and others towards timber management will have an impact on how forest lands are utilized. Other factors, such as the attractiveness of local business climates and living environments will have much to say in how future outlets for raw materials from forest land will develop. By keeping track of what is going on, we will be better able to adapt to changes and plan for the future.

RANGELANDS

A total of 78.0 million acres in the North and Great Plains are classified as rangeland (13% of the land area) (table 1). Almost all of it (77.6 million acres) is in the 4 Great Plains States—Kansas, Nebraska, North Dakota, and South Dakota. The remainder (0.4 million acres) is primarily in Minnesota and Missouri, with very small areas in New York, Wisconsin, and Iowa.

The Great Plains are known for hot, dry summers and cold, windy winters. Periodic droughts are common and precipitation is sparse. Stringers of hardwood trees (primarily in the elm-ash-cottonwood ecosystem) follow drainage systems that lace through the flat grasslands.

Great Plains rangeland is composed of two major ecosystems: the plains grasslands and the prairie. The plains grasslands is often called the short- or mixed-grass prairie and extends eastward from the foothills of the Rocky Mountains to approximately the 100th meridian, which roughly bisects the four Great Plains states (Stoddart et al. 1975). The western half of the four states, then, is part of the plains grasslands.

Short, warm-season grasses and grasses of medium stature predominate in the plains grassland, such as blue grama, western wheatgrass, needlegrass, threadleaf sedge, and needle and thread grass. Forbs and shrubs are scattered lightly over the grasslands. Plains grasses are noted for their high nutritional value and for their ability to cure well on the range. Forage may be in short supply in the spring because most species are warm-season plants. Plains grasses are resistant to heavy grazing, but with over grazing give way to weedy plants.

The prairie ecosystem, which lies between the deciduous forests of the East and the plains grasslands of the West, is also roughly delineated by elevation. The western boundary is approximately 1,500 feet above sea level, and the eastern boundary is about 500 feet.

The prairie, also known as the tall-grass or true prairie, once included much of what is now the Nation's corn belt. Only the driest portions and those parts underlain by soils too rocky for cultivation remain as the prairie ecosystem today. Big bluestem, which may reach a height of 5 to 6 feet on lowland areas, Canada wildrye, Indiangrass, switchgrass, little bluestem, and sideoats grama are some of the major grass species in the ecosystem. Large numbers of flowering forbs are present in the grass stands, but are overshadowed by the grasses. Tall-grass vegetation does not cure well on the range. Almost all grass species lose much of their nutritive value after they mature, and during the winter, domestic animals cannot thrive on these grasses unless they are fed additional protein supplements. Heavy grazing on tall grasses may result in the replacement of desirable by less desirable species (Branson 1985).

Table 11.—Ownership of Rangeland (thousand acres) in the North and Great Plains

Owner group	Area	Percent of total
Forest Service	2,617	3
Bureau of Land Management	323	1
Other Federal	732	1
Total Federal	3,672	5
Non-Federal	74,334	95
Total all owners	78,006	100

Bison once grazed the plains grasslands and the western edge of the prairie. The pronghorn antelope is still present, as is the coyote, jackrabbit, prairie dog and ground squirrel. The potholes of the northern portion of the prairie ecosystem provide an important breeding area for many species of migrating waterfowl. Mourning doves are abundant, especially near shelterbelt plantings, and sharptailed grouse and greater prairie chickens are also found in fair numbers.

Ninety-five percent (74.3 million acres) of the rangeland in the North and Great Plains is in nonfederal ownership (table 11).

WATER AREAS

Water areas in the North and Great Plains total 57.8 million acres or 54% of the Nation's water (table 1). Of the 665 million acres of land and water in the area, water accounts for 8.7%.

The North Central Region, led by Michigan, contains 75% of the water in the area. Other states with large areas of water include Wisconsin, Minnesota, New York, and Ohio. The Great Lakes, bays and estuaries on the Atlantic coast, large and small natural lakes, particularly those in the northern half of the northern tier of states, and the tributaries of the major rivers, such as the Missouri, Mississippi, and Ohio, make up most of the water area. Water impoundments, ponds, and streams comprise the remaining area of water. Water areas provide valuable fish and wildlife habitat as well as breeding and resting areas for migratory waterfowl. Water-based recreation is a large and growing use of the resource—from paddling a canoe across the glassy surface of a remote lake in the solitude of the Boundary Waters Canoe Area Wilderness in Minnesota to tubing down a Pennsylvania river that meanders through agricultural land and farm woodlots. Domestic and industrial uses round out the ways the water resource is consumed.

CHAPTER 3: THE SOUTH

LOCATION AND CHARACTERISTICS

The South includes 13 states of the Southeastern and South Central United States (fig. 2). The area stretches from Virginia southward and westward along the Atlantic and Gulf seaboards to Texas, and includes the interior states of Kentucky, Tennessee, Arkansas, and Oklahoma. This section is characterized by a variety of climatic and edaphic conditions that relate to its diverse physiography. The South covers portions of four major physiographic divisions: the Atlantic Plain, the Appalachian Highlands, the Interior Highlands, and the Interior Plains (Fennemann 1938).

The Atlantic Plain dominates the land area and consists of Coastal Plain provinces located along the Atlantic and Gulf coasts and on the alluvial plain of the Mississippi River. The climate is subtropical with rainfall averaging from 40 to 60 inches annually (USDA Forest Service 1969). The section has a long growing season, but is subject to harsh shifts in weather that include droughts, tropical storms, tornadoes, and glaze storms. Topography is relatively flat along the coast and hilly in the upper portions of the South Central Region (fig. 13). Poorly-drained low areas dissect the Coastal Plain along the many rivers and streams that flow through the area. Soils, ranging from sands to clay, are usually acidic and so strongly leached that organic matter and nutrient levels are low (Barrett 1980). Exceptions occur in bottomland areas that are rich in alluvial deposits and in the Brown Loam Bluffs adjacent to the Mississippi River Valley.

The Appalachian Highlands physiographic division includes the Piedmont, Mountain, and Plateau provinces. The Piedmont province lies parallel to the southeastern Coastal Plain, extending from Virginia to Alabama. The Mountain and Plateau provinces are oriented in belts to the west of the Piedmont. They include, from east to west, the Blue Ridge province, the Valley and Ridge province, and the Appalachian Plateau province.

The Piedmont's topography is rolling, with elevations in the 300 to 1,200 foot range. Many creeks and streams flow from the Piedmont into the Coastal Plain. The climate is more like the Coastal Plain than the Mountain province, but varies somewhat from north to south. Rainfall averages from 40 to 50 inches per year. Soils generally contain more clay than in the Coastal Plain and are subject to erosion in many areas.

The Mountain and Plateau provinces exhibit a variety of topographic features. Mountains of the Blue Ridge province are the highest, usually from 3,000 to 4,000 feet in elevation, with some peaks over 6,000 feet. The Valley and Ridge province has mountains from 2,000 to 4,000 feet that occur in long narrow belts. The Appalachian Plateaus have mountains that range from 2,000 to 4,500 feet. The Mountain and Plateau provinces typically have shorter growing seasons and cooler winter temperatures than the Piedmont and Coastal Plain. Rainfall averages between 45 and 55 inches per year. Soils are variable, depending on physiography, parent material, vegetation, and climate (Barrett 1980).

The Interior Highlands division encompasses the lower reaches of the Ozark Plateaus (including the Boston Mountains), and the Ouachita Mountains. Elevations vary from 500 feet in the Arkansas River Valley to more than 2,800 feet in the Ouachitas. The climate is humid with cool winters and hot summers. Rainfall averages roughly 45 inches per year. Soils are generally freely drained, acidic, and humus-poor (Barrett 1980).

The Interior Plains division is situated in the northwestern and southwestern portion of the South. The Interior Plains includes the Interior Low Plateaus of Kentucky, Tennessee and north Alabama, and the Central

Figure 13.—The southern landscape ranges from coastal wetlands to rugged mountains.

Lowland and Great Plains provinces of Oklahoma and Texas.

Topography of the Interior Low Plateaus ranges in elevation from 400 feet in the Nashville basin to 1,300 feet on the Highland Rim. Climatic conditions are similar to the mountains lying to the east. As with the mountains, soils vary considerably.

The Central Lowland and Great Plains provinces comprise the western portion of the South. The Central Lowlands of Oklahoma and Texas are made up of wide valleys with low relief. The Great Plains makes up the remaining land area, with topography ranging from flat to rolling plains. The climate changes from arid in the west to humid in the east.

FOREST LAND

Ecosystems

The South is heavily forested from Virginia to the forest's limit in Texas and Oklahoma. Forest land totals 203 million acres or 38% of the total land area (table 1, fig. 4). If the nontimbered western portions of Texas and Oklahoma are included, the percentage of forest increases to 54%. Five of the southern states are more than 60% forested, and most of the remaining states are at least 50% forested.

The South's 62 million acres of pine forest continue to be a major source of softwood fiber for the world (table 12). About two-thirds of the pine forest is natural in origin with the remainder consisting of planted pine stands. Many of the South's natural pine stands are now reaching maturity and are being harvested (fig. 14). On industrial properties, natural stands are typically replaced with intensively managed pine plantations. Planted pine stands currently make up 60% of industry's pine forest in the South. Harvested nonindustrial private tracts often lack adequate regeneration.

Several programs have been implemented to offset the loss of pine forests. Cost-sharing for tree planting and timber stand improvement is available through the federally-funded Forestry Incentives Program (FIP) and Agricultural Conservation Program (ACP). Rental payments are available for converting marginal cropland to trees as part of the Conservation Reserve Program (CRP) of the 1985 Farm Bill. Various state-level programs also promote pine regeneration.

Loblolly-shortleaf pine.—These forests are the South's most prevalent pine ecosystem, accounting for three-fourths of the total pine forest or 46 million acres (table 12). This ecosystem consists of pure loblolly stands, pure shortleaf stands, and mixtures of the two intermingled with other southern pine species. Natural stands often have a significant hardwood component.

Loblolly pine is the dominant species of the Coastal Plain and Piedmont provinces (McWilliams and Birdsey 1983, Sheffield and Knight 1982). It has been favored for new stand establishment over the past 30 years. Forest managers prefer loblolly because it usually exhibits rapid growth in the juvenile years. Because of its widespread occurrence, the loblolly pine ecosystem is a major supplier of timber, wildlife, and recreation resources.

Shortleaf pine is the second most common pine, but has a much wider distribution than loblolly (McWilliams et al. 1986). Shortleaf occurs in all physiographic divisions of the South; hence, it is an especially important timber species outside of loblolly's range. The heaviest concentration of shortleaf is found in the Ouachita Mountains of Arkansas. Texas, Mississippi, and Alabama are also important shortleaf pine states.

Longleaf-slash pine.—This ecosystem is important along the lower Coastal Plain. Longleaf-slash forests total 16 million acres, most of which are in Florida and southeast Georgia. The longleaf-slash pine ecosystem includes stands on a continuum from pure longleaf to pure slash pine.

Table 12.—Available forest land areas (thousand acres) in the South, by ecosystem and productivity class

		Productivity class[1]				
Ecosystem	Total	120+ cu.ft.	85 to 120 cu.ft.	50 to 85 cu.ft.	20 to 50 cu.ft.	0 to 20 cu.ft.
White-red-jack pine	514	276	102	118	18	0
Spruce-fir	18	0	0	9	9	0
Longleaf-slash pine	15,535	830	3,783	8,453	2,425	44
Loblolly-shortleaf pine	46,289	8,008	16,666	18,546	3,028	41
Oak-pine	27,799	4,413	8,754	11,624	2,984	24
Oak-hickory	74,262	5,740	18,344	33,501	12,974	3,703
Oak-gum-cypress	28,335	4,371	8,927	11,735	2,299	1,003
Elm-ash-cottonwood	3,007	627	1,078	1,152	150	0
Maple-beech-birch	877	109	206	415	146	1
Nonstocked	3,868	39	267	1,466	1,793	303
South total	200,504	24,413	58,127	87,019	25,826	5,119

[1]*A measure of mean net annual growth obtainable in cubic feet per acre in fully stocked natural stands.*

Figure 14.—Many of the South's natural pine stands are now reaching financial maturity and are being harvested.

Longleaf pine predominated over much of the lower South and up into the Appalachian Highlands prior to settlement. It was nearly eradicated following the "logging boom" of the early 1900s. A lack of information on regeneration techniques, the control of wildfire, and an indifferent attitude by the people were major causes of the decline (Croker 1987). Longleaf sites were usually reforested with loblolly or shortleaf pines. The decline of longleaf continued until very recently. Improved awareness of longleaf's benefits has led to the beginning of a comeback for the species.

Slash pine occurs naturally on wetter sites and sites protected from wildfire, but has been planted widely over the past 30 years. Planting has spread slash pine well beyond its natural range, and over half of today's stands are planted (Sheffield et al. 1983). Slash pine currently dominates the longleaf-slash pine ecosystem.

Oak-pine.—This ecosystem covers 28 million acres and is comprised of forests in which upland hardwood species are dominant, but softwoods contribute at least 25% of the stands' stocking. Oak-pine stands are scattered across the South and are very common wherever southern pine species are found. Oak-pine forests often originate on cutover pine sites with poor pine regeneration. Management of oak-pine forests offers an excellent low-cost alternative for the small private landowner (Phillips and Abercrombie 1987). The oak-pine ecosystem is important for timber, but is also outstanding in providing species richness, esthetic beauty, and wildlife habitat.

Oak-hickory.—These forests are the South's most extensive ecosystem, covering 74 million acres. Oak-hickory forests are represented by a diversity of species and sites (fig. 15). The most common mixture is the white oak-red oak-hickory association. Oak-hickory forests of the Coastal Plain are often the result of cutting practices that remove pine from pine and oak-pine stands leaving the stand to regenerate with hardwoods. The most productive oak-hickory sites of the Coastal Plain are found in the Brown Loam Bluffs of west Mississippi and west Tennessee. In the Mountain and Plateau provinces, oak-hickory forests are the primary supplier of wood, wildlife, recreation, and watershed protection. The most productive sites for timber, supporting mixed hardwood species, are the deep, well drained soils that occur on moderate slopes and cove sites (Barrett 1980). Along the western fringe of the timbered South are the post oak forests of Texas and Oklahoma. While relatively unproductive, this type provides a wealth of nontimber resources.

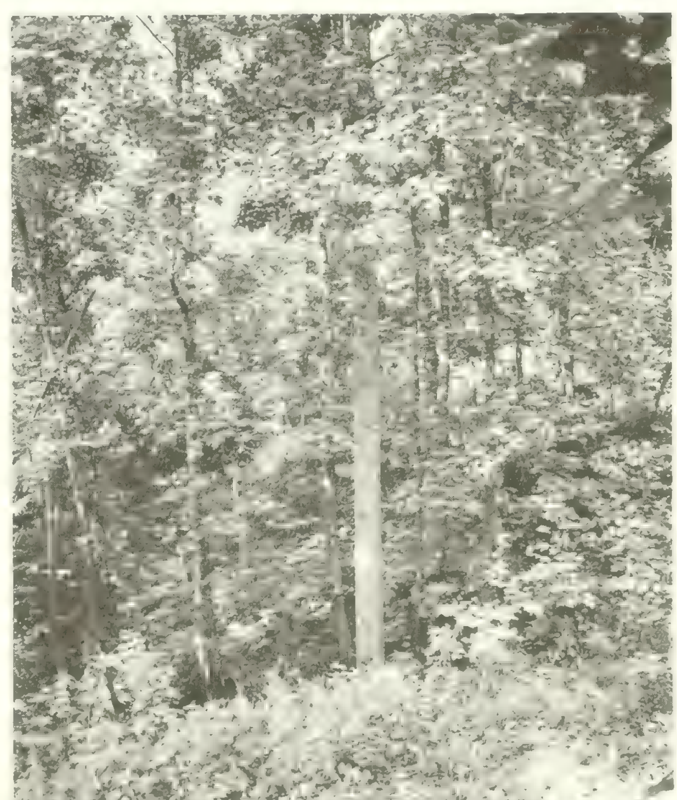


Figure 15.—Diverse oak-hickory forests are the South's most extensive ecosystem.

Bottomland hardwoods.—These forests are located throughout the South along watercourses and in low-lying, poorly drained areas. Heaviest concentrations occur in the Mississippi delta region and in Florida. Although they only occupy 16% of the total forest (31 million acres), bottomland forests contain some of the most valuable hardwood timber of the Atlantic Plain, as well as abundant wildlife habitat and recreation. Bottomland hardwoods include the oak-gum-cypress (28 million acres) and elm-ash-cottonwood (3 million acres) ecosystems.

Other ecosystems occur infrequently in the South. These include the white-red-jack pine, spruce-fir, maple-beech-birch, and pinyon-juniper ecosystems. Their importance stems from the unique habitats they contribute to the southern landscape. These ecosystems are described in detail in the North and Great Plains and Rocky Mountains sections.

Ownership

Private owners control 90% of the timberland in the South, a total of 175 million acres (USDA Forest Service in press). The remaining 10% is divided among public owners including national forests, other federal, state, county, and municipal owners. The South's 33 national forests contain 6% of the forest land. At the state level, the national forest ownership ranges from 3% of the forest land in Alabama to 14% in Arkansas. Other major federal owners include the Department of Defense and the National Park Service.

Private owners are divided into nonindustrial private forest landowners and forest industry. Nonindustrial private owners are made up of farmers, other individuals, and corporations (other than forest industry). They hold 70% of the total private forest land area. Nonindustrial private owners have a highly diverse set of ownership objectives, from purely esthetic to economic. Most nonindustrial owners are aware of the value of their timber and are not averse to harvesting when offered a reasonable price. However, timber sales are often preempted where other forest resources are valued higher than timber. In general, nonindustrial private timberland receives less active forest management than forest industry timberland. Forest management is concentrated on larger tracts and on tracts that contain a high proportion of pine timber.

Forest industry controls 20% of the South's forest land. Forest industry stands are often concentrated on more productive sites with better stocking than nonindustrial private stands (McWilliams and Birdsey 1987). Also, a much higher proportion of forest industry land is in intensively managed pine plantations.

The distribution of privately-owned forest land follows a predictable pattern in the South. Nonindustrial forests are distributed relatively evenly across the section. Very often, forest industry's holdings are either in close proximity to a pulpmill or large sawmill, or situated on the more productive sites common in the pine belt (Rosson and Doolittle 1987).

Productivity

The South's forest lands span the full range of productive capability. Some of the most extensive areas of highly productive forest lands in the United States are in this section. Long growing seasons, generally abundant rainfall, and mild climate, in combination with other favorable site conditions, often result in ideal conditions for forest growth. There are also extensive areas having a relatively low productive potential. Geologic formations and soils limit productivity in many cases. In others, the potential of today's forests has been significantly altered by human influence. A large portion of the South's land area has been in agricultural use one or more times since settlement. Many of these sites were depleted of nutrients and often suffered severe soil erosion before being abandoned. Most of these old field sites came back into forest cover and form the backbone of today's forest land.

A higher proportion of the South's forest land is in high timber productivity classes relative to other sections of the United States. About 24 million acres, or 12% of the available forest land, are capable of producing more than 120 cubic feet of wood per acre per year. Another 29% is capable of producing between 85 and 120 cubic feet annually. Together, these two classes constitute the above average sites and account for more than 40% of the available forest land (table 12). About 70% of these most productive sites are located in the South Central Region. Sites capable of producing 50 to 85 cubic feet per acre annually account for 43% of the forest land. Nearly 56% of these moderately productive sites are in the Southeast Region. Forest lands of low productive potential total 26 million acres and are about equally divided between the Southeast and South Central Regions. Most of these lands in the 20 to 50 cubic feet category of production are concentrated in the oak-hickory ecosystem. About 5 million acres of forest land in the South are incapable of producing 20 cubic feet of wood per acre annually. These areas include the post oak forests of Oklahoma and Texas and poorly drained lowland hardwood forests, primarily in Florida.

The potential yields suggested by the site productivity classes are generally not attained. For example, the average potential productivity determined by weighting the productivity classes by acres is about 88 cubic feet per acre per year for the South (excluding woodland—the 0 to 20 class). Yet, current net annual growth per acre averages less than 54 cubic feet. Only a small portion of the forest land is fully stocked with vigorous trees of the ideal species for timber production. Many acres are understocked and need various treatments in order to produce up to their potential.

The gap between potential and realized productivity in the South appears to be widening, at least temporarily. Net annual growth per acre of timberland has dropped from 57 to 54 cubic feet per acre during the past 10 years. In fact, reduced per-acre growth has been recorded in each of the last six southern states inventoried (Alabama, Louisiana, Oklahoma, South Carolina, Texas, and Virginia). Although extensive areas of productive pine

plantations are being established, most are still so young that productivity gains from these management efforts are not yet fully realized. Reduced levels of growth are concentrated in natural stands, primarily on nonindustrial private forest land. This downturn in net annual growth in the South has been documented in other studies (Knight 1987, and USDA Forest Service 1988).

The productivity of the South's forests for uses other than timber production is also diverse. Little data is available to assess these productive potentials. High productivity for other uses is complementary with timber production in some cases and not in others. Forests which are of low productivity for timber can be highly valuable for wildlife, recreation, browse production, and ecological diversity.

Use

The South's forest lands provide a range of benefits to society beyond basic timber products. Forests throughout the area provide habitat for a diversity of wildlife and fish species. Both nongame and game species alike depend on Southern forests for their existence. The importance of managing and conserving forest habitats for threatened and endangered species such as red-cockaded woodpeckers and bald eagles has recently been emphasized.

Large numbers of people are using Southern forests for recreational purposes. Although populations and associated urban areas are expanding, the South's rural charm has been maintained. Hunting, fishing, camping, and hiking are still very popular recreational pursuits in the South. Winter vacation spots abound because of the warm climate, especially along the Gulf and Atlantic coastlines. Forests add to the scenic beauty of mountainous areas, which draw millions of visitors each year. Wilderness areas provide another kind of recreative experience for large numbers of people.

The South's forest lands are also an important source of forage for cattle. With the exception of some portions of Florida, the degree of forest use for grazing is generally light in the Southeast, averaging under 10% of the forest land. Forest grazing use increases substantially as one goes west through the South Central area. More than one-fourth of the forest land in eastern Texas and Oklahoma is used for grazing.

Most of the South's forest lands provide for some combination of uses. (fig. 16). The types of use depend on the character of the land, past history, ownership, management objectives, and surrounding land uses. Southern forest lands are generally very accessible due to the nature of the landscape and land use histories. Roads are abundant and their close proximity to most forest land encourages a frequent and varied mix of uses.

Rural populations have always utilized forests extensively because they were nearby. Although much of today's forest land is still intermingled with agricultural uses, urban development is becoming an increasingly dominant component of the southern landscape. In the Southeast, one out of every five acres of forest land is within one mile of concentrations of urban development, either residential or industrial. In the South Central Region, one out of ten acres of forest land is within one mile of urban or developed land.

Figure 16.—Bottomland hardwoods forests provide valuable hardwood timber, wildlife habitat, and recreational opportunities.

Trends in Forest Area

Some two to three centuries ago, almost all land area in the South was in forest cover. The current forest resource represents a substantial erosion of that original base. Although the long-term trend has been toward less forest land, the reductions have been neither constant nor uniform. The magnitude and direction of change have been driven by a number of factors, including the need for living space and food, timber harvesting, the effects of fire control, and in more recent decades, the results of silvicultural practices. Perhaps the most influential factor driving change in forest land over the long term is the expansion and contraction of the region's agricultural land base (Healy 1985).

As the South was settled, agricultural land became an increasingly prominent part of the landscape. The associated reduction in forest area accelerated in the late 1800s with harvesting of the old-growth forests (USDA Forest Service 1988). Around 1920, increases in forest

area began in response to agricultural land abandonment, reduced timber harvesting, and efforts to regenerate forest lands. The rate of agricultural land abandonment and succession to forest was especially high during the depression years of the 1930's and after World War II. Much of the land reverting to forest on retired cropland and pasture was dominated by southern pine species.

In 1952, forests covered some 208 million acres of the South's land area. In the decade that followed, the trend toward farmland abandonment and reversion to forest cover continued. During the late 1950s and early 1960s, some 2 million acres of agricultural lands were planted to trees (USDA Forest Service 1980). By 1962, forest area had increased by 7 million acres to 215 million acres. After 1962, forest area in the South began to decline again, dropping to 208 million acres in 1970, 204 million acres in 1977, and 199 million acres in 1987. The rate of cropland abandonment slowed noticeably during the 1960s; thus, fewer acres were available to add to the forest base. In fact, forest land clearing for new cropland and pasture began to occur at an increasing rate. At first much of the clearing was concentrated in the Mississippi delta where bottomland hardwood stands were cleared for soybean production. Later, during the 1970s and early 1980s, concentrations of forest diversions for crop production spread more uniformly throughout the Coastal Plains of the South. Clearing for pasture occurred mostly in the upland areas of the South. Land area in urban and related uses has shot upward in the South during the past two to three decades, siphoning off significant areas of forest land. Both people and industry have migrated to the South in large numbers. During the 1970s and 1980s, most of the southern states experienced a net in migration of people (Healy 1985). These changes have increased withdrawals from forest land for living space and industrial sites.

A great deal of uncertainty surrounds the current forest resource and the rate at which it is changing. There are indications that the trends just described for the past 20 years might not continue unabated. The large-scale clearing of bottomland hardwoods for cropland in the Mississippi delta is not expected to continue at rates observed during the past two to three decades due to wetland conservation efforts and because much of the remaining forest area is not desirable for crop production due to the lack of flood control or drainage (Rudis and Birdsey 1986). Large-scale clearing for cropland along the southeastern Coastal Plain also appears to be tapering off for environmental and economic reasons.

The potential for forest land clearing because of growing population in the South is no doubt still large. However, the outlook for cropland needs is more uncertain (USDA Forest Service 1988). Unattractive economic returns from farming may well be creating a reservoir of land potentially available to add to the forest land base (Alig et al. 1986). Currently, many acres of marginal cropland and pasture in the South are being planted to trees as part of the Conservation Reserve Program (CRP) (fig. 17). This program could potentially put as many acres into forest cover as the Soil Bank program did 25 years ago. The full impact of the CRP and possible extent and duration of increased farmland abandonment will not be known for several years.

Figure 17.—Many acres of marginal cropland and pasture in the South are currently being planted to trees.

RANGELANDS

The South has 116 million acres of rangeland (table 1). Eighty-three percent of the rangeland is located in Texas. Oklahoma and Florida are the only other States with significant areas of range (14 and 4 million acres, respectively).

The South's rangeland is split between shrubland and grassland ecosystems. Four shrubland ecosystems are present in Oklahoma and Texas. The most prominent shrubland ecosystem is the Texas savanna situated in southern Texas. This ecosystem is a savanna with low trees and shrubs, and short to medium tall grasses. Mesquite is the most common woody plant. To the west is the southwestern shrubsteppe ecosystem, which is typified by short grasses mixed with shrubs at varying levels of intensity. The shinnery ecosystem is a midgrass

prairie with occasional stands of shrubs and low trees, occupying less than 5% of the South's rangeland. A small area of the desert shrub ecosystem is also present in Texas (Garrison et al. 1977).

The South's grasslands include four ecosystems: plains grasslands, prairie, desert grasslands in Oklahoma and Texas, and wet grasslands found in the South's coastal areas. The plains grasslands ecosystem, or Great Plains, is the largest rangeland ecosystem in the South and the Nation. In the South, it is located in northern Texas and western Oklahoma. Short grasses predominate, but rabbitbrush and mesquite also occur sporadically. The prairie ecosystem is situated on the Central Lowlands and consists mostly of extensive areas of tall grasses. The desert grasslands is an arid ecosystem in southwest Texas dominated by tobosa grass (Garrison et al. 1977).

The wet grasslands ecosystem consists of wet prairies and marshes found along the Atlantic and Gulf coastlines, and also includes the Everglades and palmetto prairie of southern Florida (Garrison et al. 1977). Well over half of the wet grasslands ecosystem is located in Florida. Louisiana and Texas also contain significant areas of coastal prairies and marsh.

Aside from their importance as a producer of forage for domestic livestock, rangelands of the South offer a multitude of scenic and recreational resources, and are also extremely important for providing unique habitat for several species of threatened and endangered species. The golden-cheeked warbler, Texas red wolf, Attwater's prairie chicken, Florida panther, Florida great white heron, and Everglades kite are some examples. Several other species of wildlife, such as the collared peccary, coatimundi, and pronghorn antelope, are also unique to the rangelands.

WATER AREAS

Water areas in the South cover some 2 million acres, 4% of the total area in the region (table 13). Florida and Louisiana have the highest concentrations of water—10% or more of the total area in each of these two states. North Carolina, Texas, and Virginia each contain large areas of water. Inland water makes up more than four-fifths of the South's water total.

The major bodies of inland water include the lower Mississippi River and tributaries, lakes and waterways of the Mississippi delta, large numbers of small and large lakes in Florida, and numerous large water impoundments constructed across the South. Small ponds and streams plus Atlantic and Gulf coastal waters make up the remaining area of water.

The South's water areas provide valuable habitat for fish and wildlife. They are used by migratory birds overwintering and thereby directly affect the wildlife resources of other regions. Water areas ranging from small farm ponds to coastal waters provide important sites for water-based recreation activities. Domestic and industrial consumption of water is also an extremely important use.

Table 13.—Water areas (thousand acres) of the South, by region, and State

Region and state	Total water area	Inland water			Other water[3]
		Total	Large areas[1]	Small areas[2]	
Southeast					
Florida	4,467	3,357	2,887	470	1,110
Georgia	897	866	546	320	31
North Carolina	2,714	2,714	2,480	234	0
South Carolina	909	821	592	229	88
Virginia	1,792	825	681	144	967
Total	10,779	8,583	7,186	1,397	2.196
South Central					
Alabama	1,193	835	633	202	358
Arkansas	914	914	705	209	0
Kentucky	514	514	474	40	0
Louisiana	3,338	2,688	2,354	334	650
Mississippi	1,056	700	345	355	356
Oklahoma	990	990	797	193	0
Tennessee	762	762	649	113	0
Texas	3,792	3,739	2,993	749	53
Total	12,559	11,142	8,950	2,192	1,417
South total	23,338	19,725	16,136	3,589	3,613

[1]*Lakes and ponds at least 40 acres in size; waterways 1/8 mile or more in width.*
[2]*Lakes and ponds between 2 and 40 acres in size; waterways less than 1/8 mile in width.*
[3]*Atlantic and Gulf Coastal waters.*
Source: Forest Service RPA data base, 1987.

CHAPTER 4: THE ROCKY MOUNTAINS

LOCATION AND CHARACTERISTICS

The eight States making up the Rocky Mountain Section (Montana, Idaho, Wyoming, Utah, Nevada, Colorado, Arizona, and New Mexico) cover about 863,531 square miles which is roughly 552.7 million acres (fig. 2 and table 1). The land area within these States totals 546.6 million acres, nearly a fourth of the entire Nation.

A variety of land forms provide the scenic landscapes for which the Rocky Mountain States are famous (fig. 18). The plains rolling westward into the eastern extremes of these states give way to the steep glaciated terrain of the Rocky Mountains. These states are also characterized by high elevation interior basins and plateaus, and highly eroded tablelands, particularly in Arizona, Utah, Wyoming, and western Colorado. This section also has extensive areas of arid desert in Arizona and New Mexico.

The dry climate in this section is labeled "semiarid continental", because evaporation usually exceeds precipitation even though maximum rainfall occurs in the summer months. Winters are cold and dry, the summers warm to hot. Winter precipitation is largely in the form of snow and is greater in the mountains than in the more plains-like areas. Moisture is the most limiting factor for plant growth. The principal soil-forming process is calcification with salinization on poorly drained soils. Soils are generally rich in bases and often contain an excess of precipitated calcium carbonate. Except in forested areas, the organic matter content is low, and in many areas the soils are thin and fragile.

FOREST LAND

More than 138 million acres, roughly 25% of the land area in this section, are occupied by forests, predominantly of softwood species. Almost half the total forest land is in the three States of Colorado, Idaho, and Montana. Although Montana has a slightly larger forest area, Idaho has nearly as much and is the most heavily forested, with more than 41% of its land area taken up by forest land. The percent of total land area that is forested in the eight Rocky Mountain states is as follows:

State	Percent forested
Idaho	41.4
Colorado	32.2
Utah	30.9
Arizona	26.7
New Mexico	23.9
Montana	23.6
Wyoming	16.1
Nevada	12.7

Forest land in the Rocky Mountain states has two components—timberland and woodland. Timberland forests are those whose species traditionally have been used for industrial roundwood products such as veneer and sawlogs, pulpwood, and poles. Woodland forest species have generally not been used for industrial products because of form and stature; wood product uses are generally limited to fenceposts and fuelwood. In past classifications of forest land, woodlands have usually been categorized as unproductive or "other" forest land. In the Rocky Mountain states, woodlands occur as either pinyon-juniper (softwoods) or chaparral-mountain shrub (hardwoods). In terms of area, there is more pinyon-juniper forest than any other type (figure 19). It makes up 34% of the total forest land in the Rocky Mountains (table 14).

A sometimes confusing situation regarding pinyon-juniper and chaparral-mountain shrub lands is that although they are considered forest land, their primary use is grazing, making them major range ecosystems.

The distribution of forest ecosystems and other vegetational zones is largely a function of growth environment (soils, moisture, and temperature), which is affected by latitude, elevation, aspect or slope exposure, and prevailing wind direction. Generally, more similar vegetational zones occur at higher elevations in the south than in the north because of temperature and moisture regimens.

Figure 18.—Land forms and vegetation offer a variety of scenic landscapes in the Rocky Mountain States.

Figure 19.—Pinyon-juniper land is a major forest as well as rangeland ecosystem.

Ecosystems

Five forest ecosystems totaling some 112 million acres make up about 80% of the forest land in the Rocky Mountain states—pinyon-juniper, Douglas-fir, fir-spruce, ponderosa pine, and lodgepole pine (table 14). All but pinyon-juniper are important for wood products. Other major softwood ecosystems are largely confined to Idaho and Montana. Hardwood species have wide ranges throughout much of the Rocky Mountain States area.

Timberland

Ponderosa pine.—The ponderosa pine ecosystem is found to some extent in all the Rocky Mountain states (fig. 5). It covers about 16.5 million acres, nearly half of which is in Arizona and New Mexico. It is usually the first timberland forest ecosystem encountered above the desert floor and often grows in pure stands, especially in the southwest. In Idaho and Montana, ponderosa pine is often associated with Douglas-fir, larch, and other species requiring more moisture.

Douglas-fir.—In the Rocky Mountains, this ecosystem usually occupies elevations immediately above the ponderosa pine zone and below the fir-spruce; however, in some situations the Douglas-fir and ponderosa pine zones are reversed. More than 13 million of the 17.9 million acres of this ecosystem are in Idaho and Montana. Pure stands of Douglas-fir are found where it has developed as a climax forest in northern Colorado, and in parts of Wyoming and Utah. In Montana and northern Idaho where moisture is abundant, Engelmann spruce and western larch are common associates and are often the dominant species in the ecosystem. In terms of timber production, the Douglas-fir ecosystem is second only to ponderosa pine in the Rocky Mountain states.

Lodgepole pine.—The lodgepole pine ecosystem typically consists of pure, or nearly pure, and often very dense, stands of the species. There are 14.6 million acres in the Rocky Mountain states, 55% of which is in Idaho and Montana. Most of the rest is in Wyoming and central Colorado. Lodgepole pine stands are frequently replaced through succession by other softwood species such as Douglas-fir, grand fir, and subalpine fir. But it is not uncommon for pure stands of lodgepole pine to take on the appearance of a climax type. Dense stands in this ecosystem usually have no understory vegetation.

Fir-spruce.—This ecosystem is found in high elevation areas where temperatures are cool and moisture abundant. Most of its 16 million acres are in the higher latitudes and elevations of Idaho, Montana, Wyoming, Utah, and Colorado. Grand fir, subalpine fir, and Engelmann spruce are the major species. In the northern Rocky Mountains, larch, western redcedar, and western white pine are common associates. In Colorado, Wyoming, and Utah, this ecosystem forms picture postcard landscapes at timberline.

Others.—The western white pine, larch, and hemlock ecosystems comprise less than 3% of the total forest land in the Rocky Mountain states and are restricted to Idaho and Montana. The western white pine ecosystem occupies the same general temperature belt as Douglas-fir—moist sites above ponderosa pine and below the fir-spruce. This subclimax type generally has a mixture of western redcedar, western hemlock, grand fir, Douglas-fir, and western larch, with ponderosa pine at lower

Table 14.—Area of forest land (thousand acres) in the Rocky Mountain states by major ecosystem, 1987

State	Total	Douglas-fir	Ponderosa pine	Western white pine	Fir-spruce	Hemlock-Sitka spruce	Larch	Lodgepole pine	Redwood	Other softwoods	Western hardwoods	Pinyon-juniper	Chaparral	Nonstocked
Arizona	19,384	263	3,786	0	417	0	0	0	0	840	1,050	12,918	0	111
Colorado	21,338	1,930	2,369	0	4,432	0	0	2,219	0	96	4,239	5,745	0	308
Idaho	21,818	6,586	2,040	226	4,354	1,322	890	3,154	0	1,079	970	513	0	685
Montana	21,910	6,553	2,773	36	2,162	179	927	4,844	0	2,480	481	83	0	1,392
Nevada	8,927	19	78	1	220	3	0	28	0	180	310	7,982	77	31
New Mexico	18,526	1,016	3,401	0	772	0	0	0	0	1,184	897	10,089	0	1,169
Utah	16,233	839	521	0	1,604	0	0	664	0	223	2,914	9,316	12	139
Wyoming	9,966	736	1,544	0	2,178	0	0	3,641	0	297	514	709	0	347
Rocky Mountain Total	138,104	17,942	16,511	263	16,139	1,504	1,817	14,550	0	6,379	11,374	47,354	88	4,182

Note: Data may not add to totals because of rounding.
Source: Forest Service RPA data base, 1987.

elevations, and includes Engelmann spruce at higher elevations.

The larch ecosystem is, for the most part, confined to the area west of the Continental Divide in Montana and north of the Salmon River in Idaho. Western larch is a deciduous conifer that often is perpetuated as a subclimax species by fire, much the same as lodgepole pine. In some parts of northern Idaho, it is a pioneer species following fire or other severe disturbance. On cooler, more moist sites, it mixes with Douglas-fir and grand fir; on drier sites with ponderosa pine.

The hemlock ecosystem has both western and mountain hemlock as major species. Mountain hemlock is found at high elevations in association with whitebark pine, subalpine fir, and Engelmann spruce up to timberline. At elevations below 6,000 feet, western hemlock is the major associate. In areas where western redcedar is a major associate, the ecosystem may represent a climax forest; where present areas of the ecosystem have established following fires, less shade-tolerant, subclimax species such as white pine and Douglas-fir are retained. About 88% of this ecosystem is in Idaho.

The 11 million acres of hardwoods in the Rocky Mountain States include woodland species such as oak. Timberland hardwoods consist primarily of two species, quaking aspen and cottonwood. In the high country, aspen is usually found as small patches or groups of patches punctuating the mountainsides as landscape decorations. However, in Colorado and Utah where two-thirds of the aspen is located, there are rather extensive areas. Aspen, a relatively short-lived species (up to 120 years), is nearly always replaced by coniferous species, particularly species of spruce and fir, in the normal successional scheme. It is the only hardwood in the Rocky Mountains managed for timber production. At lower elevations, the hardwoods are represented by cottonwood, usually found along streambanks and in the low valleys.

Woodland

Pinyon-juniper.—The pinyon-juniper ecosystem covers some 47 million acres, principally on the dry plateaus and broken tablelands of Arizona, New Mexico, western Colorado, Utah, and Nevada. In Arizona and New Mexico it is the predominant forest type. It is a rather uniform type, with few tree species, generally occupying an elevational zone (4,500 to 7,500 feet) above the desert floor and below ponderosa pine. The species composition changes geographically and can vary from pure pinyon pine to pure juniper.

Chaparral-mountain shrub.—In the Rocky Mountain states, this ecosystem is characterized by the presence of oak species and mountain-mahogany (*Cercocarpus* spp.). In the northern areas, gambel oak and other deciduous shrubs are dominant, but give way to evergreen species in Arizona and New Mexico. Included in this ecosystem are large areas of oak-juniper woodlands in the southwest.

Additional information about the vegetation of the pinyon-juniper and chaparral-mountain shrub ecosystems is included below in the rangeland subsection.

Ownership

In the Rocky Mountain states, three-fourths of the forest land is publicly owned (Green et al. 1983). Federal agencies, principally the Forest Service, administer 94 million acres or two-thirds of the total. In no state is less than half the forest land under federal jurisdiction and several states have much more: Nevada, 86%; Idaho, 77%; Utah, 74%; and Montana, 72%. Except in Nevada and Utah where the Bureau of Land Management has the major holdings, the Forest Service is the chief caretaker, managing over 67 million acres—nearly half of all forest lands.

The timberland area that is not reserved from cutting has generally the same ownership pattern. Roughly 75% is publicly owned; 60% is in national forests. Other public lands are mostly state-owned, with the largest holdings in Idaho and Montana. Much of the state-owned land is in scattered tracts (two sections per township), as a result of the original disposition of federal lands through grants in the 1800s. Isolation and tract size often cause problems in administration and management of such lands. Most of the 3 million acres of industry-owned timberland is in Montana and Idaho; most privately owned nonindustrial land is in Idaho, Montana, Colorado, and New Mexico.

Productivity

Based on the capacity of the land to produce wood fiber, the productivity of forest land in the Rocky Mountain states is low compared to other major timber-producing areas in the United States. Scant precipitation and thin soils over much of the area, and short growing seasons at higher elevations, are major factors. About half the forest land cannot produce 20 cubic feet of wood per acre per year, the standard below which forest land is considered unproductive. For the most part, these are the pinyon-juniper woodlands.

Even the timberlands are low on the productivity scale. Over half of the timberland cannot produce 50 cubic feet per acre per year, and only 11 million acres are highly productive and can produce more than 85 cubic feet per acre per year.

Most of these highly productive lands are in Idaho and Montana, and roughly 75 % is in national forests. There is some variation in productivity among ecosystems mainly attributable to soil/moisture relationships characteristic of the sites on which trees grow. The most productive sites are generally occupied by the hemlock-cedar, Douglas-fir, and fir-spruce forest types.

At the other end of the scale are the pinyon-juniper woodlands. The very nature of this ecosystem and the climatic conditions where it occurs, preclude any substantial growth rates. However, the 47 million acres of this ecosystem have high value for a variety of resource uses.

Use

The use of forest land in the Rocky Mountain states is moving away from a preoccupation with timber toward less consumptive uses associated with other resource

values. For example, recreation/tourism is a big and growing business in the Rockies. The attraction is an almost endless array of forest landscapes whose environments include a variety of wildlife, water, and other resources and values. Because three-fourths of the forest lands in the Rocky Mountain states are publicly owned, the use and management of these lands depend on what the people want from them.

The future use of the forests will be dictated largely by public land-use policies that reflect public goals. Any single use emphasis at local levels will continue to be given a lot of emotional and scientific (if not judicial) attention. The principal concern of the public is whether prospective supplies of all outputs from the forest are able to meet increasing demands while maintaining the integrity of the land base and enhancing the environment.

Trends In Forest Area

Lack of early historical data makes tracking trends in forest areas in the Rocky Mountain states difficult. Some land was cleared for settlement, and forests were exploited to fulfill the needs of economic and territorial expansion—railroad ties, mine timbers, and charcoal for ore reduction. However, most of the cutover areas have reverted back to forest.

In recent decades, there has been a modest, but steady, decline in the nonreserved forest land base throughout the section. Substantial areas of privately owned forest land have been subdivided for homesites, particularly in Montana, Idaho, and Colorado, and some public lands have been included in the National Wilderness Preservation System or set aside for other special uses.

Future prospects are for the forest land acreage to remain fairly stable. However, allocation of forest land for various uses likely will change. Clearing for roads, urban development, power transmission rights-of-way, and surface mining will surely continue. Both productive and relatively unproductive land will be affected, but the extent of change is unknown. Although there will be declines in the areas used to produce timber, most other resource uses and values should be available and maintained.

RANGELANDS

Ecosystems

The rangeland ecosystems of the Rocky Mountain states are extremely diverse due to great variation in climate, precipitation, and elevation. These ecosystems make up almost one-half of the Nation's rangelands, and include woodland, shrubland, and grassland. Two forest ecosystems described in the woodland section, pinyon-juniper and chaparral-mountain shrub, are included in the rangeland section because their predominant use has traditionally been as range. Woodland can be characterized as unproductive forest land, which is incapable of producing annually 20 cubic feet per acre of industrial wood under natural conditions because of such adverse site conditions as sterile soils, dry climate, poor drainage, high elevation, and steepness or rockiness. The total rangeland area, including these woodlands, is about 336 million acres, or 61% of the total land base of this section (table 1).

The classification scheme used for describing the major rangeland ecosystems of the Rocky Mountains is that of Garrison et al. (1977). Other sources of information include Branson (1985), Stoddart et al. (1975), and USDA Forest Service (1981).

Woodland

Pinyon-juniper.—The pinyon-juniper type is often composed of a mix of both species, but juniper species occupy by far the most acreage. The area of the western United States covered by pinyon-juniper forests is currently estimated at more than 47 million acres (table 14). The most extensive stands occur in Nevada, Utah, Arizona, New Mexico, and Colorado, with additional occurrence in Idaho and Wyoming. Species of pinyon pine include common, singleleaf, and Mexican. Junipers include oneseed, Utah, Rocky Mountain, and alligator. Associated species include mountain-mahogany, cliffrose, bluebunch wheatgrass, blue grama, galleta, Indian ricegrass, sideoats grama, needlegrasses, and muhlys.

Annual precipitation on these lands is from 12 to 18 inches, and soils are relatively coarse. Densities vary from scattered trees in grasslands to dense stands with little or no understory. This type is usually found between 4,500 and 7,500 feet elevation.

In the past, the pinyon-juniper forests have been removed by chaining and burned to increase forage production for livestock. However, in the last decade, the value and importance of pinyon-juniper wood for fuel, and of pinyon-juniper forests for wildlife habitat, recreation, and commercial harvest of pinyon nuts have gained increasing recognition.

Chaparral-mountain shrub.—Intermingled with and below the pinyon-juniper lies the chaparral-mountain shrub type; a sort of discontinuous foothill transition zone between coniferous forest and grass or shrublands. The term chaparral refers to dense stands of evergreen and shrubby vegetation, and is represented in the Rocky Mountains mainly in Arizona by scrub live oak. Other scrub oak types, not strictly chaparral, occupy vast areas in the West, especially in the southwest. These include evergreen and deciduous oaks such as gambel, wavyleaf, emory, and gray. Mountain shrub species include maple, mountain-mahogany, serviceberry, chokecherry, and buckbrush.

The chaparral and oak types are usually composed of close-growing species, forming dense stands with low grazing potential. The mountain shrub areas are usually more open, with considerable grass and forb understory. Both ecosystems are typified by rough topography and low-to-moderate precipitation (10 to 28 inches annually). These types cover about 8 million acres in the Rocky Mountain States (USDA Forest Service 1981).

Shrubland

Sagebrush.—The sagebrush type is the second largest range ecosystem in the United States with roughly 105 million acres, most of which occurs in the Rocky Mountains.

This broad, cold-desert ecosystem occupies vast plains and plateaus in Idaho, Nevada, Oregon and Wyoming, and is found in all the other Rocky Mountain States. Big sagebrush, the dominant species, occurs on a variety of wet and dry sites as well as strongly alkaline and nonalkaline soils. Different varieties and species occur at elevations from 5,000 to 10,000 feet and receive from 6 to 20 inches of annual precipitation.

Other species are black, low, and silver sagebrush, associated with wheatgrasses, fescues, bluegrasses, and bromes. Most of the land within this type is used for sheep and cattle grazing, mostly in the spring and fall. Some of the land in this type will support irrigated ranching if enough water is available. Antelope use the sagebrush zone for habitat year-round, and it can be important for deer winter range.

Southwestern shrubsteppe.—Throughout southern Arizona, New Mexico and Texas, the southwestern shrubsteppe occupies roughly 27 million acres of nearly level desert plains. Much of this area was once primarily grassland, but has been modified into shrubland through livestock grazing. Yucca is one of the most characteristic woody plants, along with mesquite, tarbush, and creosote bush. Black grama, three-awns, tobosa, and sideoats grama are commonly occurring grasses. Cover ranges from predominantly shrubs with occasional grass to nearly all grass. Annual precipitation is as low as 10 inches in the west to 18 inches in the east. Elevationally, this type occurs below the pinyon-juniper.

Desert shrub.—An arid climate, poorly developed soils, and sparse vegetation characterize the desert shrub ecosystem. It includes the salt-desert shrub type of the cold desert. This type occurs below 5,500 feet in the Great Basin and includes shrubs that are salt-tolerant, such as saltbush, greasewood, and pickleweed.

This ecosystem also includes the hot-desert mesquite bosques and cactus-shrub communities of the southwest. These communities include mesquite, bursage, creosote bush, palo verde, pricklypear, cholla, saguaro, and several desert grasses.

Precipitation throughout the ecosystem is very low (5 to 10 inches annually). The salt-desert shrub type is used mainly for winter range for sheep. The mesquite bosques have high forage production potential, especially when the mesquite cover is reduced. This ecosystem covers about 58 million acres.

Grassland

Grasslands represent some of the most productive rangelands of the world, yet their range value is being diminished through cultivation, heavy grazing, and shrub encroachment. Woody vegetation is favored by grazing and control of fire.

Mountain grasslands.—Ecologically, grasslands occur between the wetter forests and the drier desert shrublands. The mountain grassland ecosystem covers about 17 million acres and is characterized by bunchgrasses. This ecosystem consists mainly of open, untimbered areas, yet may interface with ponderosa pine, Douglas-fir, lodgepole pine, or even spruce-fir forests at high elevation. This type also sometimes borders the sagebrush zone in the foothills. Annual precipitation is about 20 inches; it can be as much as 30 inches at the higher elevations.

Bluebunch wheatgrass, Idaho fescue, needle-and-thread grass, Sandberg bluegrass, and junegrass are the common grasses of this ecosystem. Desirable forbs may be abundant. Wildrye is a grass common to the bottomlands. Where native grass cover has been removed, cheatgrass usually invades.

Low elevation land that has not been cultivated is valuable spring and fall range for livestock, and may also be critical winter range for big game. At high elevations, this type is prime summer range for livestock and big game. This ecosystem includes many prime watershed and recreation lands.

Mountain meadows.—This ecosystem usually occurs in wet or moist valleys and basin-like areas in the forest zones of the Rocky Mountains. The plant community is usually composed of hairgrasses, bluegrasses, sedges, rushes, and some water-loving shrubs such as willow. These scattered areas comprise a small part of the rangeland in the West—only 2 million acres.

These areas are sensitive to abuse, and many small meadows have been destroyed (or severely damaged) through road and trail building and overuse by livestock or campers. Some meadows within large expanses of forest land are critical for wildlife use by both big game and waterfowl. These meadows also provide good grazing for livestock.

Desert grasslands.—In close proximity to the southwestern shrubsteppe type in the southwestern states, the desert grasslands occupy roughly 22 million acres. These grasslands occur at elevations less than 4,200 feet, and are the driest of the grasslands, receiving only 8 to 15 inches of annual precipitation. The single most important grass species is black grama, with curlymesquite, three-awns, blue grama, tobosa, and galleta as additional members of the plant communities. Shrub cover increases at the lower and higher elevations of this zone. Shrub cover includes mesquite, yucca, creosote bush, and pricklypear.

Plains grassland.—The grasslands to the east of the Rocky Mountains probably developed as a result of the rain shadow caused by the mountains, which along with fire eliminated forest from all but the lowlands. The most productive parts of these grasslands have been converted to cropland.

The plains grassland ecosystem is often called the short- or mixed-grass prairie; it forms a continuous zone into New Mexico in the South and to mid-Nebraska, Kansas, and the Dakotas on the east. This is the largest rangeland ecosystem in the United States. In the Rocky Mountain states, this type covers about 87 million acres.

Precipitation increases eastward from about 12 inches to 20. The predominant grasses are blue grama and buffalo grass. These short, warm-season grasses are remarkably resistant to damage from grazing, but under heavy use may give way to weedy shrubs such as snakeweed and pricklypear.

Ownership

About 167.4 million acres (50%) of the rangeland in the Rocky Mountain states is in public ownership, mostly in the care of federal agencies:

Owner group	Thousand Acres	Percent of total
Forest Service	33,482	10
Bureau of Land Management	125,558	38
Other Federal	8,371	2
Total Federal	167,411	50
Non Federal	168,407	50
TOTAL	335,818	100

In Nevada, federal agencies administer 92% of all rangelands.

Productivity

Productivity of the rangeland ecosystems in the Rocky Mountain states is highly variable. The woodlands may produce from 0 to 2,000 pounds of herbage per acre annually, with the chaparral-mountain shrub type averaging from 1,000 to 2,000 pounds per acre. Shrublands have a similar range of productivity, with sagebrush having the highest. In desert grasslands, herbage production is never much greater than 1,000 pounds per acre. The other extreme is the mountain meadow type, which may produce as much as 4,000 pounds of herbage per acre. The shortgrass plains type averages under 2,000 pounds per acre, with mountain grasslands nearer 3,000. As a rule of thumb, 30 to 40% of herbage can be utilized as forage (Garrison et al. 1977).

Use

One of the dominant uses of all these lands has traditionally been livestock grazing. Some of these lands are well suited for grazing, but others have been irreversibly changed by it, due to decrease in plant cover and soil loss. Other uses of rangeland are for watersheds, wildlife habitat, timber, and recreation. Rangelands also have less tangible values such as esthetics and clean air. Some of what was originally rangeland is now under cultivation or development. Any management and use of rangelands should involve balancing the various ecological components—soil, vegetation, water, animals, climate, fire, and topography—to maintain the stability of the ecosystems.

Trends In Rangeland Area

The range of pinyon-juniper is thought to have increased since European settlement due to over-grazing, fire suppression, and climatic changes, but no real data are available, however, on the extent of the changes.

The most productive areas of the grasslands and sagebrush types have already been converted to cropland. Where it is still economically feasible, mechanical or chemical means are used to remove woody vegetation such as sagebrush, pinyon-juniper, or mesquite to increase grass cover for livestock forage. A much more widespread trend is that of shrub encroachment on native grasslands, which is caused by poor grazing management and control of fire.

WATER AREAS

It is no surprise that the Rocky Mountain Section is the driest in the country in terms of rainfall. Water is indeed at a premium. The section has the smallest water area—in both absolute and relative terms—of all the sections.

The total water area (all is inland water) is only about 6.0 million acres (table 1), a mere 1% of the total geographic area of the section, and only about 10% of all the inland water in the United States. More simply stated, these eight states have about a fourth of the total land area and a tenth of the inland water in the country.

Over half (55%) of the Rocky Mountain states' water is in Utah and Montana. Utah alone has 32% of the section's water. Unfortunately, much of it is in (or ends up in) the Great Salt Lake, where it has very limited value.

In addition to the Great Salt Lake, water areas include the upper Missouri (Montana), the Snake (Idaho), and the Colorado (Colorado, Utah, and Arizona) river systems. These major river systems, and others less widely known, have both large impoundments and smaller storage reservoirs. In addition, this mountainous section of the country is laced with many smaller streams and dotted with thousands of lakes, although such waters are minimal in Arizona and Nevada.

Although the amount of inland water in the Rocky Mountain states is relatively small, it is of great importance to the Nation as well as the section. It supports large fish and wildlife populations and is the focal point for many outdoor recreation activities for several million people. But more importantly, the Rocky Mountain States provide much of the water for domestic use and irrigation of the cropland from the Mississippi River through the arid southwest and on into southern California.

CHAPTER 5: THE PACIFIC COAST

LOCATION AND CHARACTERISTICS

The Pacific Coast Section includes the four mainland states of Alaska, California, Oregon, and Washington; and the island state of Hawaii. With a land area of 570 million acres, these five states contain one-fourth of the total area in the Nation.

The latitudinal span of the mainland states is 38 degrees—71 degrees north at Point Barrow, Alaska to 33 degrees north at the southern border of California. The Hawaiian Islands, stretching from 28 degrees north to 18 degrees north, bring the total reach of the Pacific States up to 53 degrees of latitude, from north of the arctic circle to the tropics. The extremes of environmental conditions attributable to latitudinal spread in this vast region are moderated in many areas, and exagerated in others, by the influences of ocean currents, prevailing winds, and land form. In the mainland states are four major climatic zones — arctic, maritime, continental, and mediterranean (Bailey 1978).

In the arctic zone of Alaska's northern and western coastal plains precipitation is minimal (10 inches per year or less), surface winds are strong and frequent, and permafrost is extensive in the wet tundra soils. In most of this area forests are absent, or reduced to shrub thickets.

The maritime climatic zone extends from the south-central coast of Alaska to the central coast of California. This zone is characterized by mild, wet winters, and relatively cool, humid summers. Annual precipitation ranges from more than 150 inches in places in coastal Alaska and western Washington to less than 30 inches in some of the "rain shadow" valleys between the Coast Range and Cascades in Oregon and Washington. In Alaska and California the maritime zone is a narrow band along the coast, with steep mountains, deep canyons, and little flat ground in coastal plains or valleys. In Oregon and Washington the maritime zone encompasses most of the area west of the crest of the Cascade Range. Some of the most productive forest soils in the world are found in this area; but soils of very low productivity can also be found — on steep slopes and ridgetops, in poorly drained areas, on peridotite and serpentine rock, and on geologically recent lava flows.

In the maritime zone are some of the tallest trees in the world, and the most productive coniferous forests in the northern hemisphere. The redwood belt of California, the spruce and hemlock forests of coastal Alaska, and the Pacific Northwest Region west of the Cascade Mountains in Oregon and Washington are within the maritime zone.

The continental climatic zone includes Alaska's interior, where subarctic conditions occur, and the warmer inland region east of the Cascade and Sierra Nevada Mountains in Washington, Oregon and California. Winter and summer temperatures in Alaska's interior vary up to 100 °F, precipitation is low, and permafrost is common. Forests are much less productive here than in Alaska's coastal belt. The inland area of Oregon, Washington, and California is similar to the Rocky Mountain Section, with forested mountains and plateaus rising above sagebrush steppe and grassland. Precipitation ranges from less than 10 inches in arid valleys to more than 60 inches in some mountainous areas. Forests of inland Oregon, Washington, and California are less productive, on the average, than those in the maritime zone. The better sites, however, are quite productive, yielding high quality ponderosa pine, western larch, true fir, and inland Douglas-fir.

The mediterranean climatic zone includes most of California (that east and south of the maritime strip, and west of the continental zone). Winters are mild and moist, and summers are extremely hot and dry. Extremely variable topography and complex geology within this zone produce areas of treeless grasslands, extensive shrublands, oak savannas, dense hardwood forests, and coniferous forests, some as tall and productive as those in the maritime zone.

The Hawaiian Islands, though tropical by location, enjoy the cooling effect of the northeast trade winds. Temperatures at most locations in Hawaii's lowlands vary relatively little over the year—from a record maximum of 88 °F, and a record minimum of 57 °F with a mean annual temperature of 75 °F at Honolulu. Temperatures vary greatly by elevation, and windward locations tend to be cooler than leeward ones. Precipitation is highly variable from place to place, ranging from about 7 inches on the leeward coast of Hawaii to about 480 inches at Mount Waialeale on Kauai. The soils in the Hawaiian Islands, developed from volcanic ash and basaltic lava under a wide range of conditions, produce some of the most varied flora in the world.

FOREST LAND

Forests cover 220 million acres, or 39%, of the land area in the Pacific Coast States (table 1). This amounts to 30% of the total forest area in the Nation. Productive timberland, both reserved and available, totals about 85 million acres. Productive timberland is capable of growing 20 or more cubic feet of industrial wood per acre per year on a continuous basis. Other forest land totals 135 million acres. Included are pinyon-juniper woodland, hardwood savanna, chaparral, and extensive areas of coniferous timber species on land incapable of growing 20 cubic feet of industrial wood per acre per year, or on land that cannot be managed for timber on a continuous

basis because of steepness, rockiness, poor drainage, or other environmental factors.

Ecosystems

In this discussion the term "ecosystem" is synonymous with the term "forest type." Forest types were classified during recent extensive forest inventories according to the predominant tree species, whether or not they formed "climax" types or were of economic value. Because of the large number of species types, it was necessary to group specific types into broader type categories. Also, some local type names have been renamed. For example, about 8 million acres of forests in California are classified locally as mixed conifer type, often containing five or more tree species in varying proportions. Ponderosa pine is almost always present in these stands, and frequently predominates. In this discussion the California mixed conifer type is grouped with ponderosa pine type.

Douglas-fir.—This type covers about 21 million acres of forest land. It is the most important forest type, in terms of timber production, in the Pacific Coast Section. The best sites are capable of yielding more than 200 cubic feet per acre per year. Forty-two percent of the type is capable of producing more than 120 cubic feet.

Douglas-fir is the major type in western Oregon and western Washington, where it occupies nearly 60% of the forest area. It is found in the Cascade Mountains from midslopes in the north and mid-to-upper slopes in the south, in the central lowlands, and throughout the Coast Range, as well as in northwestern California, where it covers about 1.1 million acres. Included in the 21 million acres of Douglas-fir type are 4 million acres scattered through the ponderosa pine ecosystem in eastern Oregon and eastern Washington.

The Douglas-fir type is actually a collection of many different plant communities. The most common coniferous tree species associated with Douglas-fir are western hemlock and western redcedar. Others include Pacific silver fir, noble fir, grand fir, Sitka spruce, Port Orford cedar, Alaska cedar, incense-cedar, western larch, western white pine, sugar pine, and ponderosa pine. Hardwoods such as red alder, bigleaf maple, black cottonwood, Oregon white oak and Pacific madrone are also common associates of Douglas-fir.

Hemlock-Sitka spruce.—About 16 million acres of this ecosystem is covered by hemlock-Sitka spruce—11 million acres in coastal Alaska, 5 million in Oregon and Washington; fewer than 50,000 acres are in north-coastal California. Four major local types are included in this type: western hemlock, Sitka spruce, western redcedar, and mountain hemlock-subalpine fir. In Alaska, the four local types intermingle and Alaska-cedar becomes an important component. In Oregon and Washington Sitka spruce occurs only in the narrow coastal fog belt and amounts to less than 300,000 acres of the 5 million acres in the hemlock-Sitka spruce type there.

Stands of Sitka spruce on deep soil are among the most productive coniferous forests in the world, yielding as much as 400 cubic feet of wood per acre per year. Western hemlock on the best sites is capable of yielding 250 cubic feet per acre. However, the average productivity of the hemlock-Sitka spruce type group is somewhat less than that of Douglas-fir, with 36% capable of producing 120 or more cubic feet (42% of the Douglas-fir type can produce 120 or more).

Hemlock-Sitka spruce type tolerates a narrower range of environmental conditions than Douglas-fir, and for that reason the list of associated tree species is somewhat shorter. In Alaska, associated conifer species found in the type include primarily western hemlock, mountain hemlock, western redcedar, Alaska-cedar, Sitka spruce, and lodgepole pine. Many coastal forest stands often contain only two or three tree species. In the mountains away from the coast in Oregon and Washington stands generally are more diverse. Hardwoods are occasionally found in the hemlock-Sitka spruce type, often as pioneer species on disturbed sites.

Redwood.—The redwood ecosystem covers about 1.2 million acres. Six thousand acres are in southwestern Oregon and the rest is in California. Redwood is restricted to the narrow summer-fog belt near the Pacific Ocean.

Redwood is the most productive coniferous forest type in the U.S. and probably in the world. The best sites yield more than 400 cubic feet of wood per acre per year. Eighty-nine percent of the redwood type is capable of producing 120 or more cubic feet, and 97% can produce at least 85 cubic feet. Unlike most conifers, redwood can sprout from stumps or roots of cut trees, and several sprouts often originate from one stump. The rapid early growth and high density of young redwood stands on logged over land are attributable to redwood's ability to resprout when cut.

Despite the restrictive environmental requirements of redwood, quite a large number of tree species grow with it. Associated conifers may include grand fir, western hemlock, Sitka spruce, western redcedar, Port Orford cedar, Douglas-fir, Bishop pine, Monterey pine, knobcone pine, shore pine, Pacific yew, California nutmeg, and two species of cypress. Hardwoods include tanoak, Pacific madrone, bigleaf maple, California-laurel, California buckeye, cascara, two species of deciduous oak, and three species of live oak.

Fir-spruce.—This is the most extensive forest type in the Pacific Coast Section. In Alaska, the fir-spruce type (which contains no true fir species), is usually associated with hardwoods, or follows hardwoods in ecological succession. The fir-spruce/hardwood forests cover 116 million acres (white spruce and black spruce total 94 million; hardwoods total 22 million). Almost all of this is in Alaska's interior. About 14 million acres are classified as productive timberland, although none produces over 180 cubic feet per acre per year. The remaining 102 million acres of fir-spruce/hardwood type in Alaska are classifed as "woodland," forest on sites incapable of growing 20 cubic feet of wood per acre per year because of harsh climate, permafrost, shallow or poorly drained soil, or other environmental factors. Three major ecosystems comprise Alaska's fir-spruce/hardwood type:

bottomland spruce/poplar, upland spruce/hardwood and lowland spruce/hardwood.

In Oregon, Washington, and California, fir-spruce type covers 12 million acres, most of which is productive timberland. In Oregon and Washington the type consists of stands in which the following species, singly or in combination, predominate: white fir, grand fir, subalpine fir, Pacific silver fir, noble fir, Shasta red fir, Engelmann spruce, and Brewer spruce (found only in one county). In California the type consists primarily of white fir, grand fir, California red fir, and Shasta red fir.

In Oregon and Washington the fir-spruce type is found at higher elevations in the moist Cascades and Coast Range Mountains, and in the drier inland mountains. Growing conditions in these settings are somewhat harsher than for neighboring forest types. Only 8% of the type in Oregon and Washington is capable of producing 120 or more cubic feet of wood per acre per year, and 21% is capable of growing 85 or more. Quite a different situation exists in California where 26% of the true fir type is capable of growing 120 or more cubic feet, and 48% can grow at least 85 cubic feet.

Ponderosa pine.—About 14 million acres are covered by this ecosystem, of which 12.5 million acres are productive timberland. Included are the ponderosa pine stands of eastern Oregon and eastern Washington; ponderosa and Jeffrey pine stands of southwestern Oregon and California; and the California mixed conifer type, which consists of ponderosa pine and/or Jeffrey pine, sugar pine, white fir, incense-cedar, Douglas-fir, California black oak, and occasionally other hardwoods. Among the other species associated with ponderosa pine in Washington and Oregon are grand fir, western larch, western white pine, lodgepole pine, Engelmann spruce, Oregon white oak, and western juniper. In California, Coulter pine, knobcone pine, Digger pine, western juniper, cypress, canyon live oak, Oregon white oak, and several other hardwoods can be found.

The very best ponderosa pine sites can yield well over 200 cubic feet of wood per acre per year, but 77% of the pine sites are not capable of producing more than 85. Only 10% can yield more than 120 cubic feet. The three major pines in this type—ponderosa, Jeffrey, and sugar—are long-lived species that grow to large size.

Unproductive ponderosa pine "woodland" covers about 1.5 million acres. Included are pine stands in arid forest fringe areas, on lava flows and other rocky sites, and on soils derived from serpentine and peridotite rock. In such areas, forest stands are sparse and trees are short and poorly formed.

Lodgepole pine.—This ecosystem, including both the coastal "shore pine" and the inland or mountain form, covers about 3.6 million acres in the Pacific Coast states, where it ranges from southeastern Alaska to southern California. The inland or mountain form is by far the most extensive. It is found in the mountains of the drier interior of Oregon, Washington, and California, and on the pumice flats of central Oregon. Associated species over this range include many conifers and several hardwoods, although pure stands are fairly common.

Lodgepole pine stands in the Pacific Coast states tend to be less productive on the average than lodgepole in the Rocky Mountains. Only 7% of the type is capable of producing 85 or more cubic feet of wood per acre per year (compared with 14% in the Rockies).

Miscellaneous conifers.—Several other forest types with limited area are found in the Pacific Coast states: western white pine, western larch, subalpine larch, Coulter pine, Bishop pine, Monterey pine, Torrey pine, knobcone pine, Digger pine, foxtail pine, bristlecone pine, limber pine, whitebark pine, Pacific yew, several species of cypress, and others. Collectively, they cover about 6.2 million acres. Some of these types are quite productive, and/or are important locally, for many purposes. Two species have been planted extensively in other parts of the world—Monterey pine as a timber species, and Monterey cypress as an ornamental and coastal zone windbreak species.

Mainland Hardwoods

Mainland hardwoods, excluding those in Alaska's interior forests, cover 14.1 million acres. About 6.4 million acres are productive timberland. In southeast Alaska, red alder and black cottonwood stands are common along streams, but are not extensive. In Oregon and Washington red alder is the most extensive hardwood type. Other types there include bigleaf maple, black cottonwood, Pacific madrone, Oregon white oak, and, in southwestern Oregon, tanoak. In California, tanoak is the major hardwood type on productive forest land, followed by California black oak and several minor hardwoods. Except for those in bottomlands and narrow riparian strips, most of the hardwood stands occupy sites where conifers grew in the past. Logging, fires, and other disturbance have allowed hardwood species to invade or expand on these sites.

In western Washington and northwestern Oregon hardwoods are often found on the very best conifer sites; on most of these sites, the productivity would be greater for conifers. In some cases, however, short-term hardwood yields may be higher than potential conifer yields. About 56% of the hardwood types are on sites capable of yielding 120 or more cubic feet of wood per year, and 77% can produce at least 85.

Unproductive hardwood "woodland" types cover 7.7 million acres, most of which is in California. Unlike the hardwood types on productive timberland, the woodland hardwoods are usually climax types. They occupy the transition zone between conifer forests at higher elevations and treeless grasslands at lower elevations. Most of this area is referred to as "oak woodland," or "oak savanna," because oak species predominate. In Washington and northern Oregon, the oak is Oregon white oak. In southern Oregon, California black oak, canyon live oak, and several other hardwoods appear. Oregon white oak is common in northern California. Blue oak is the most extensive type statewide (amounting to nearly 3 million acres). Other oak types in California include coast live oak, canyon live oak, interior live oak, valley oak, California black oak, and Engelmann oak.

Productivity and stand dynamics in Pacific Coast oak woodlands are not well understood. Oaks are not regenerating in many areas; but the reasons are not clear. So although stand volumes of 2,500 to 4,000 cubic feet per acre are fairly common, without information on how long (or what) it takes to establish new stands, potential yields in these types cannot be determined.

Pinyon-juniper.—This ecosystem covers about 5 million acres, including 2.5 million in eastern Oregon, and 2.5 million in California. The pinyon-juniper type in the Pacific Coast states represents the western edge of the extensive pinyon-juniper ecosystem of the semi-arid West. Appearing and disappearing as topography dictates, pinyon-juniper types cover about 50 million acres. In Washington, although pinyon-juniper is absent as a type, scattered Rocky Mountain juniper and western juniper trees can be found. Western juniper type is extensive in eastern Oregon where Rocky Mountain juniper trees also occur in a very few locations. In California, the western juniper type occurs east of the Cascades and Sierra Nevada Mountains in the north, merging with Utah juniper and singleleaf pinyon along the Nevada border. California juniper occurs in southern California, and in scattered locations to the north.

The California total wood volume in trees 3 inches and larger in diameter at root crown averages 580 cubic feet per acre in pinyon-juniper stands, and 325 cubic feet per acre in western juniper stands. Mean annual increment over the life of the average stand ranges from 5 to 10 cubic feet per acre. Western juniper trees are typically straight and single-stemmed, and often reach heights of 40 feet or more. Other species of juniper, and pinyon pine tend to be shorter, crooked, and multi-stemmed. Therefore, western juniper stands, though producing less total wood volume then pinyon-juniper, produce more volume of industrial wood (in straight logs at least 8 feet long to a 4-inch top). Western juniper stands average 170 cubic feet of industrial wood per acre compared with 103 cubic feet for pinyon-juniper.

The durability of juniper wood makes it desirable for fence posts. The average number of fence posts that could be cut from an acre of western juniper is about 110, compared with only 10 from pinyon-juniper stands.

Chaparral.—Chaparral covers 7.6 million acres in the Pacific Coast states, most of which is within the mediterranean climatic zone in California. Chaparral type is made up of several species of large shrubs or dwarf trees which are well adapted to survive the long dry summers, periodic torrential storms, and recurring wildfires common in its range. Common species include chamise, manzanita, ceanothus, mountain-mahogany, sumac, buckthorn, toyon, silktassel, California buckeye, and several species of shrubby oaks.

Chaparral stands are typically very dense and range from 3 to 15 feet high. Biomass productivity of chaparral varies by type. Annual increments of total aboveground woody biomass of .25 to .50 tons per acre have been measured in chamise stands; .5 to 1.8 tons in ceanothus stands; .25 to 1.25 tons in scrub oak. Many chaparral sites can be successfully converted to productive grass land, but without careful maintenance, most of these conversions eventually revert to chaparral (Conrad and Oechel 1982, Wakimoto and Menke 1978).

Hawaiian Islands

The Hawaiian Island ecosystems are diverse and can be classified according to whether they occur on the dry, leeward side of an island, or the wet, windward side; and their elevational position. The vegetation of the leeward lowlands consists mostly of introduced plants in a grassland or savanna setting, such as kiawe (mesquite) and haole koa (leucaena). Above the lowlands on the leeward side are evergreen scrub and forest, consisting mostly of exotic trees or tree-like shrubs such as guava, Java plum, and Christmasberry. On the windward side of the islands evergreen rain forests predominate, characterized by ohia and koa, both native. They account for more than 800,000 acres of the 1.7 million acres of forest land in the State. Ohio is the most abundant. On Maui and Hawaii, the two highest islands, rain forests are replaced at about 6,000 feet by mountain parkland and savanna. Koa and mamane, both native legumes, are prominent trees in this zone. Above the parkland and savanna is the alpine scrub, and finally, alpine tundra on the highest peaks (Buck, 1987).

The productivity of Hawaii's forests is variable. Forests on recent lava flows are relatively unproductive. Productivity of deep soil forest sites is very high.

Greatest yields measured are in plantations of exotics such as eucalyptus, where annual height growth as great as 10 feet has been measured.

Ownership, Uses, and Trends in Forest Area

Of the 220 million acres of forest land in the 5-state area, 72 million acres are privately owned. Of the 145 million acres in public ownership, 46 million are in national forests; the remaining 99 million acres are held by various public agencies, including state, county, municipal, and other federal agencies (Bureau of Land Management, Department of Defense, National Park Service, Bureau of Indian Affairs, and others). Percentage distribution by owner group is: private, 33%; national forests, 21%; other public, 46%.

Forests in the Pacific Coast states, like those elsewhere, are used for many purposes. To some degree all categories of forest use occur in all states. The particular mix of forest uses depends on ecosystem, ownership, institutional constraints, economics, and the wishes of society. A discusison of ownership, use, and trends by individual Pacific Coast states follows.

Alaska

Distribution of forest land in public and private ownership has changed dramatically in the past decade as a result of three national legislative acts—the Alaska Statehood Act of 1958, the Alaska Native Claims Settlement

Act of 1971, and the Alaska National Interest Lands Conservation Act. Previously, almost 95% of the forest in Alaska was administered by the federal agencies. The Forest Service administered about 11 million acres in the southeastern coastal area; the Bureau of Land Management (BLM) administered ten times that area, including most of the state's interior. Much of the land formerly administered by the BLM is now distributed among private individuals, Alaska Native corporations, and state agencies. The final disposition is yet to be made on some lands being considered for ownership transaction. Private ownership currently represents 38% of Alaska's forest land; the state owns 32%; and 30% is federally owned.

The sector of Alaska's economy based on timber is relatively small, despite the vast forest area. In perspective, it ranks with tourism, behind oil and fisheries. Large-scale forest commodity production is limited to coastal, southeastern Alaska where the productive Sitka spruce-hemlock forests provide resources for sawn products, chips and pulp. Relatively little industrial use is made of interior forests because of their low productivity, relative inaccessibility, and great distance from processing facilities and markets. Fuelwood, lumber, and sided houselogs produced by part-time mills for local use, are the major wood products of the interior. A few cabinet-makers use the local birch and cottonwood in their trade.

While vast changes have occurred in Alaska's forest ownership pattern, the bulk of the highly productive coastal forests remains in national forests. They have provided most of the wood used in mills in that area for several decades. (By law, all timber harvested from federal lands in Alaska must be processed initially in Alaska before it can be exported). In the past ten years a substantial area of national forest land has been reserved as wilderness areas, which currently amount to about 1.6 million acres. This leaves 4.5 million acres of productive timberland available for resource management in national forests in the coastal area. While researchers have provided guidelines and techniques for managing Alaska's coastal forests for timber production, and fish and wildlife habitat protection and enhancement, controversy has heightened over the disposition of many areas outside wilderness boundaries. Disagreements have also arisen over how areas dedicated to resource production are to be managed—what logging method, what size cutting unit, what rotation length, what species to feature, whether or not to salvage dead trees, etc. Past trends would suggest that a smaller area of national forest land will be available for timber production in the future, but it will be more productive. Whether or not the reduced area of forest managed for timber production can supply as much wood as is now being harvested in old growth stands is uncertain.

The increase in privately owned forest in Alaska is expected to affect trends in use. Included are 694,000 acres of productive coastal timberland and 5.5 million acres of productive forest in the interior. Timber harvested from these lands is now exempt from the law requiring primary processing in Alaska. This could affect local economies and the price of stumpage. It could also have long-term effects on resource allocation and protection.

California

California is rich in renewable resources and has the second greatest area of forest in the Nation, with 39.4 million acres. The state has a long history of industrial use of its forests; for several decades it has ranked among the top four states in the Nation in production of softwood commodities. California is now the scene of a kind of civil war between those who depend on traditional resource-extractive industries and those who would put an end to such industries in the state. In numerous localities throughout the state, rural areas are becoming urbanized. While resource conflicts and trade-offs are most obvious at the *physical* forest-urban interface; economic, political, and social forces with epicenters far from the forests are having the most profound effect on trends in use and forest ownership.

Physical losses of forest land during the past 10 years have been rather minimal, despite increasing urbanization, road and reservoir construction, and other activities. Timberland losses amounted to less than 300,000 acres, or about 0.2% per year. Loss of woodland amounted to another 200,000 acres or 0.1% per year. Road and reservior construction usurped forest on both public and private lands, but urbanization—the single greatest factor—was confined to private lands.

Forest ownership is an important criterion in assessing trends in resource use. On the surface it would appear that forest ownership in California has been fairly static. The current distribution, shown in the following tabulation, is similar to that for 1975:

Ownership	**Million Acres**	**Percent**
National Forest	17.1	44
Other public	5.1	13
Private	16.7	43
Total	38.9	100

Within different ownerships, some notable changes have occurred that influence trends in use. Recent wilderness additions in national forests have increased the total area of reserved forest by about 1.1 million acres, and the area of reserved productive timberland by 450,000 acres. In the other public category, additions to national, state, and local parks amount to less than 100,000 acres. Management of national forests and other public lands has come under critical scrutiny by many interest groups, favoring either increased or decreased use of public resources in the marketplace.

National forests have supplied about 1.5 to 1.8 billion board feet of timber annually for many years (not counting the dip in timber harvest during the 1981-82 "timber recession"). This is about 38 to 40% of the state's total.

Private forest owners provided more than 70% of the wood used by forest industries before 1965, and about

60% since then. In 1986, 2.3 billion board feet were cut on private lands. An estimate based on a canvass of forest products mills indicates that 1.9 billion board feet came from forest industry lands, and 400 million came from farmer and miscellaneous private lands.

Private timberlands in California have been classified into three categories: 1) forest industry with mill(s) (timber companies that own land and manufacture forest products); 2) forest industry without mill(s) (large corporate ownerships on which the primary use of the land is growing and harvesting timber, although the owners do not operate mills); and 3) farmer and miscellaneous private (individual or corporate owners whose primary use of the land is for purposes other than growing timber). The following tabulation shows the distribution of these ownerships in California and the percent in timberland production zones (TPZ)[3].

Ownership Class	**Million acres**	**Percent TPZ**
Forest industry with mill(s)	2.8	95 +
Forest industry without mill(s)	1.4	95 +
Farmer and miscellaneous private	3.3	39
Total	7.5	

In the past ten years several hundred thousand acres of timberland owned by companies that operated mills have changed ownership. Some of the new owners do not operate mills, although the land is still being managed for timber production. In some cases the land stayed in the same ownership, but the mills were sold. Most industrial land transactions have been followed by notable changes in management, and these potential changes in practices on a significant proportion of California's timberland are viewed with concern by state resource planners and policy makers.

Almost all of the physical loss of private forest land in California during the past ten years has been in the farmer and miscellaneous private category and primarily to urban development. Of the 3.3 million acres in farmer and miscellaneous private ownership, 1.3 million acres are in timberland production zones, and are less likely to be developed within the near future. The remaining 2.0 million acres are vulnerable to development.

Timberland production zones do not guarantee that forest land will remain in resource use: zones are in effect for only 10 years, and owners may appeal for zoning changes. A study by Romm and others (1983) examined many factors in relation to forest owner attitudes toward forest management, such as place of residence, age, level of education, personal financial status, and size of property. This study showed that land owners were more likely to favor timber management if wood products accounted for a high percentage of total employment in the county in which the property was located. It seems safe to say, however, that a large percentage of the farmer and miscellaneous private forest land will not be managed for timber, and is likely to be converted to nonforest use.

The appearance and condition of California's forests have changed markedly in the past ten years as a result of wildfires, insect and disease infestations, extremes of weather (both drought and flood), natural stand growth and development, timber harvesting, and other human activities. In 1987, an unusually bad year for fires, nearly 1 million acres burned, of which more than 250,000 were timbered. The fires killed an estimated 2.3 billion board feet of timber and 90,000 acres of young plantations. Although less spectacular than fire, insects and diseases killed 4 times the volume of timber and affected several times the area burned during the period 1975-1985.

The greatest change in forest condition in the past 10 years, however, is attributable to logging, which removed about 37 billion board feet of timber from several million acres and is changing the character of the forest—from rather open stands of large, old trees, to dense stands of small, young trees. In the north coastal redwood-Douglas-fir belt, for example ,the size of the average sawtimber tree decreased over the past 10 years from about 25 inches to 20 inches (average tree volume decreased from 620 board feet to 410). At the same time, the total number of trees increased by 55%. The mix of species has also changed. In coastal areas hardwoods burgeoned as the conifers were harvested; in the interior, tolerant species such as white fir and incense-cedar increased as pines were removed from mixed-conifer stands.

Forest industrial consumption in California is dominated by lumber manufacturing to a much greater extent than in Oregon or Washington. Between 1976 and 1985 the proportion of the total harvest that went into producing lumber increased from 86% to 92%. Veneer and plywood production declined sharply, from 11% to 5%.

Oregon

With 28.1 million acres of forest land, Oregon ranks third in the U.S. in forest area and fourth in area of timberland (2.1 million acres of timberland are reserved in parks and wilderness). It ranks first in total volume of available timber with 68 billion cubic feet. For several decades, it has also ranked first in volume of timber harvested.

Ownership distribution of forest land in Oregon is as follows:

Ownership	**Million Acres**	**Percent**
National Forest	12.6	45
Other Public	5.1	18
Forest Industry With Mills	5.4	19
Forest Industry Without Mills	0.5	2
Farmer and Miscellaneous Private	4.5	16
Total	28.1	100

[3]Timberland production zones were recognized by the California Forest Taxation Reform Act of 1976 as lands on which growing timber is the highest and best use. Taxes are assessed on a reduced basis and in such a manner as to remove the incentive to cut stands prematurely.

Public ownerships account for 63% of the forest in Oregon. Included in the national forest total are 10.2 million acres of available timberland, 1.6 million acres of timberland in wilderness and other reserves, and 0.9 million acres of woodland. On national forest timberland, sites capable of producing 120 or more cubic feet of wood per acre amount to only 9% of the total, compared with 53% of forest industry lands and 45% of other private. In 1985 about 3.5 billion board feet of timber were cut on Oregon national forests. This is 43% of the total volume harvested in the state (from 47% of the available timberland). Unique to Oregon is the relatively large area of forest managed by the Bureau of Land Management (BLM)—2.7 million acres, of which 2.0 million acres is highly productive timberland. In 1985 BLM lands supplied about 900,000 million board feet of timber, 11% of the state's total, from 9% of the state's available timberland.

Other categories of public lands include state, county, municipal, and miscellaneous federal owners (National Parks, Department of Defense, and others). Indian lands managed under the guidance of the Bureau of Indian Affairs are also included in the public ownership category, though strictly speaking, they are private lands. The other public ownerships combined supplied about 425 million board feet in 1985, about 5% of the state's total.

In 1985, 3.0 billion board feet were harvested from forest industry lands. This is 37% of the total volume of timber harvested in Oregon, yet these industry lands account for only 19% of the timberland area. Companies that do not operate mills own extensive areas of forest dedicated to timber growing—primarily in the western part of the state.

Farmer and miscellaneous private forest lands include both small and large tracts owned by individuals as well as corporations. Although 45% of the timberland in this ownership is capable of yielding 120 or more cubic feet per acre, much of it is not being managed for timber production. Accounting for 16% of the timberland, this ownership contributed only 4% of Oregon's timber harvested in 1985.

A number of changes in Oregon's forest land base have occurred during the past 10 years. Within national forests, a nominal amount of new road construction, sizable additions to wilderness, and other decisions have reduced the total area of available timberland by about 1.3 million acres, or 11%. On BLM land, 448,000 acres of timberland were reserved from timber production; about 15,000 acres of forest were replaced by new roads.

Some erosion of the privately owned forest land base has occurred during the past 10 years. Within the timberland zone, losses amounted to less than 1%, mostly resulting from road-building. In the mixed-forest-agriculture zone losses amounted to about 3%; pasture clearing was the major cause. In the mixed-forest-urban zone, losses amounted to about 4%; as would be expected, urban-development and road-building were the major causes.

Most of the reduction in private forest area has been on farmer and miscellaneous private lands. However, some noteworthy changes in ownership concerning forest industry lands are occurring. A substantial acreage of timber company property has been acquired by aggressive investment groups and international financiers. Another development is the acquisition of timbered properties by corporations based in Japan, People's Republic of China and Taiwan to secure timber for export. In most cases the land is not held by the foreign corporation after the timber has been harvested, but is reforested according to state law, then sold intact as timberland. These events may have important long-term effects on resources, local economies, and the environment.

The most obvious change in Oregon's forests over the past 10 years has been the reduction in area of old growth forests by logging, and the corresponding increase in area occupied by seedlings and saplings, especially on public lands (fig. 20). Much of the old growth on private lands was liquidated more than 10 years ago. On industrial private lands there has been a definite improvement in condition of the forest in terms of its ability to produce future crops of softwoods: in 1976 about 79% was occupied by manageable conifer stands; by 1986 this increased to 84%. Farmer and miscellaneous private lands have generally remained static, with about 64% that are well stocked with conifers in 1976 and 1986. Areas lacking manageable conifer stands are occupied by hardwoods, and inhibiting vegetation. Hardwoods have increased in area and volume for several decades on all ownerships, and have generally been regarded as weeds because they compete with conifers and have had little value on the market. The value of hardwoods, especially red alder, has been increasing recently, and timberland managers are beginning to look at hardwoods as a resource to manage.

The major uses of Oregon timber have been for lumber, veneer and plywood. Between 1976 and 1985 the relative amount of lumber produced from Oregon timber increased slightly from 58% of total wood consumption to 60%.

Plywood and veneer production declined from 35% to 30%. Production of pulp, posts, poles, pilings, and shakes and shingles decreased slightly while log exports increased—from 5% to 8% of total wood consumption.

Numerous forest-related issues have emerged, some involving the possible restriction of tree cutting in riparian strips. Other controversies represent regional or national issues and involve rare and endangered plants or animals, such as the provision of adequate spotted owl habitat, and protection of the Columbia River Gorge.

Washington

Forest land totals 21.9 million acres in Washington, placing the state sixth in forest area in the Nation. Forests cover 46% of the land, making Washington the most heavily forested state west of the Mississippi. Ninety percent of the state's forests is productive timberland, most of which supports stands of Douglas-fir, western hemlock, ponderosa pine, and other conifers. With 64 billion

Figure 20.—By far the greatest change in Pacific Coast forests has been the reduction in area of old growth.

cubic feet, the state ranks a close second to Oregon in total volume of available timber. It ranks second to Oregon also, in total volume of timber harvested annually.

Ownership of Washington's forest is distributed as follows:

Ownership	Million Acres	Percent
National Forest	7.6	35
Other Public	5.6	25
Forest Industry	4.8	22
Farmer & Miscellaneous Private	3.9	18
Total	21.9	100

About 4.9 million acres of the 7.6 million acres of forest in national forests is available timberland, a reduction of about 0.3 million since 1975. Changes on both the plus and minus side include reserved area additions,

new road construction, expansion of ski areas, land acquisitions and deletions, and reclassification of some lands. Timber harvested from national forests in Washington has averaged about 1.2 billion board feet per year in recent years, about 20% of the total for the state.

Of the 5.6 million acres of forest in other public ownership, about 3.8 million are available timberland. The balance is split between productive timberland, primarily in national parks, and unproductive forest. Of the 3.8 million acres of available timberland, the State of Washington is the largest owner, with over 2 million acres. In 1985 about 1 billion board feet of timber was harvested on state lands, 17% of Washington's total, from 12% of the timberland. This was a sizable increase over the average of about 600 million harvested during the previous 4 years. About 1.4 million acres of timberland listed as other public are Indian lands. These are private lands owned by individuals or tribes, and are managed under the guidance of the Bureau of Indian Affairs. Indian lands have been contributing 200 to 300 million board feet, or roughly 4% of the total annual timber harvest in the state. Other public forests as a group are generally in good condition for continued timber production—88% are occupied by manageable conifer stands.

Forest industry lands in Washington have been undergoing some of the same kind of changes that have occurred in Oregon and California, with shifts between those companies with mills and those without, buyouts, and takeovers.

A large acreage, however, is held by companies that have remained fairly stable through the recent period of rapid change. Between 1965 and 1980, forest industry ownership increased by roughly 400,000 acres as forest industries acquired timberland, mostly from farmer and miscellaneous private owners. In recent years over 3 billion board feet have been cut annually on forest industry lands, about 55% of the total timber cut in the state from 22% of the forest land. Condition of the forest remains good on industry lands, with 88% occupied by manageable conifer stands.

Forest area in farmer and miscellaneous private ownership has been declining, mainly to urban expansion near major cities. From 1965 to 1980, about 270,000 acres of forest were lost. On the average these forests are in poorer condition than those in other ownerships: 78% are stocked with manageable stands, and 22% are occupied by cull trees, hardwoods, and brush. Farmer and miscellaneous private forest lands have been supplying about 10% of the wood consumed by forest industries in the state. About 900,000 acres of forest land in this ownership group is intermingled with areas developed for urban, industrial and agricultural uses. Much of these latter forests will probably be converted to nonforest in the future, and the remainder will probably not be used for continuous timber production.

In the past 10 years lumber production in Washington has remained fairly constant, but veneer and plywood, pulp, and post, pole and piling, and shake and shingle production have decreased. A major shift is the change in log exports, which between 1974 and 1984 increased 44%, from 1.6 billion board feet to 2.3 billion. Market and economic factors are responsible for most of the shifts, but declining availability of old growth western red cedar is thought to be the reason for the reduced production of shakes and shingles.

Other major changes in Washington during the past 10 years include a continued reduction in area and volume of old-growth timber (most notable in national forests because much of the old growth had already been logged on other lands); widespread tree mortality in eastern Washington caused by the combined effects of dwarf mistletoe, bark beetles, and budworms; and the eruption of Mount St. Helens, which directly affected about 125,000 acres of available timberland and killed 580 million cubic feet of live timber.

Hawaii

Forests in the Hawaiian Islands cover 1.7 million acres, including 800,000 acres of productive timberland and 900,000 acres of woodland. There is little federal ownership of forest land in Hawaii, and no national forests. Hawaii's forest reserve system contains over 840,000 acres, most of which is owned by the state. Privately owned land within restrictive Conservation Districts totals 327,000 acres. There is little commercial wood harvesting on these lands.

Some wood harvesting is done of native koa, an attractive wood resembling black walnut and used for flooring, paneling, furniture and specialty items. Fast-growing exotic hardwoods are harvested for wood energy products on the island of Hawaii. Most of Hawaii's 46,000 acres of exotic plantations are eucalyptus.

The primary and essential resource produced in Hawaiian forests is water. Most of Hawaii's water supply comes from underground aquifers which are recharged by subsurface flow from forested watersheds. Some watersheds near cities are totally restricted from other use.

The protection and preservation of the unique endemic flora and fauna of Hawaii is a high priority. There is interest in sustaining or expanding production of a broad range of forest products, including koa specialty items, biomass from planted eucalyptus, tree fern products, various items made from plant parts gathered in the forest, and many more. In some areas, livestock grazing is the main use of the land, and in these areas the forests have been cleared or thinned to promote forage growth. Recreational uses of Hawaii's forests include hunting, fishing, hiking and sight-seeing, and tourism centered around the Islands' unique natural and cultural histories.

RANGELANDS

The total area of rangeland in the five Pacific Coast states is 241 million acres (table 1). Not included are extensive areas of chaparral, pinyon-juniper, oak woodland, and conifer timber stands that are grazed by

livestock. If counted, these types would bring the total rangeland area up to well over 300 million acres. Pacific Coast rangelands can be classified into three broad ecosystem groups, identified by their location: those in Alaska; those in the three lower mainland states of California, Oregon and Washington; and those in Hawaii.

Alaska

Alaska has about 173 million acres of rangeland, most of which is arctic and alpine tundra. In the Arctic tundra and Bering tundra provinces, cottongrass-tussock is widespread. Associated vegetation includes sedges, lichens, mosses, and forbs, along with several species of dwarf shrubs, including willows, birch, Labrador-tea, blueberry, and cinquefoil. In the Brooks Range region, lower elevations may be vegetated with a productive mat of sedges and shrubs. Cottongrass, bluejoint, mosses, lichens, forbs, and several species of dwarf shrubs are common. At higher elevations plant cover is discontinuous. Barren rock is intermingled with low mats of mosses, lichens, forbs, dwarf birch, crowberry, Labrador-tea, willow, and blueberry. Alpine tundra also occurs in the Alaska Range, north to the Yukon River. Extensive bogs occupy old river terraces, ponds, and sloughs. Vegetation there is chiefly sphagnum and other mosses, aquatic forbs, sedges, bog rosemary, and Labrador-tea.

Alaskan rangelands are variable in productivity. Though the cottongrass-sedge-dwarf shrub and bluejoint types can produce up to 1,000 pounds of forage per acre, most rangeland areas produce well under 500 pounds. These rangelands support large populations of caribou, moose, and about 30,000 reindeer. They also support numerous other animals indirectly through the food chain, including bears, wolves, coyotes, foxes, squirrels, mice, and many others.

Ownership of rangelands in Alaska has changed dramatically in the past 10 years. Formerly, about 97% was in federal ownership, most managed by the BLM. The BLM now manages 59 million acres, about 34%.

The Forest Service administers 2.5 million acres. The remainder is held by private owners (mostly native Alaskans), the State of Alaska, and other federal agencies, such as the National Park Service.

Important to the livelihood of some native Alaskans are the reindeer, which supply meat, milk, hides and horns. The lichens of the arctic tundra are critical for the subsistence of the reindeer. It is estimated that about 40% of the lichen resource has been severely damaged by overgrazing and recurring wildfires. The Soil Conservation Service is working with other groups including native Alaskans, University of Alaska, and other government agencies to study growth and management of lichens, to develop and apply improved range management techniques to these lands (critical because of the long time required to revegetate overgrazed lichens), to provide technical assistance in making range site inventories, and to study the population dynamics of reindeer (Galt 1988).

California, Oregon, and Washington

The rangeland ecosytems in these three states are similar to those of the Rocky Mountain Section. Total rangeland area is about 71 million acres, including 23 million acres of grassland and 48 million acres of shrublands. Not included are about 8 million acres of chaparral, 7 million acres of oak woodland, 5 million acres of pinyon-juniper woodland, and 4 million acres of other conifer woodland, most of which produce forage, and are grazed.

Grasslands are divided into mountain grasslands (40%), mountain meadows (6%), annual grasslands (41%), alpine grasslands (13%), and wet grasslands (trace). Mountain grasslands are found in all three states. Plant species present in this ecosystem vary considerably from place to place, but commonly include species of wheatgrass, fescue, brome, needlegrass, bluegrass, wild rye, balsamroot, wyethia, rabbitbrush, sagebrush, and bitterbrush. Mountain meadows are also found in all three states, but are more common in California. Bluegrass, pinegrass, fescue, sedges, false hellebore, lupine, buckwheat, and numerous small forbs are typically found in mountain meadows. Alpine grasslands, also found in all three states above timberline, may contain species of bluegrass, fescue, brome, needlegrass, sedges, phlox, lupine, buckwheat, gilia, penstemon, avens, aster, buttercup and numerous other small forbs. Annual grasslands, found in the foothills surrounding the Great Central Valley in California, are dominated by introduced annuals that have replaced the native perennial bunchgrass (most of which was needlegrass). Among the annuals that now occupy these extensive grasslands are wild oats, fescue, brome, barley, dogtail grass, medusahead, and numerous forbs including filaree, dock, poppy, mountain dandelion, lotus, clover, and tarweed. The annual grasslands merge with the oak woodlands at higher elevations in the foothills. Annual grassland plants are common in much of the blue oak, interior live oak and valley oak woodland types. For this reason the oak woodlands and "savannas" are often considered to be part of the California annual grasslands (Barbour and Major 1977).

Shrublands are divided into sagebrush (52%) and desert shrub (48%). The sagebrush ecosystem includes several major and numerous minor associations. Most extensive is the big sagebrush group in which one of the several varieties of *Artemisia tridentata* dominates. Other shrubs may include rabbitbrush, bitterbrush, mountain-mahogany, granite gilia, currant, serviceberry, and snowberry. Common grasses are fescue, wildrye, wheatgrass, bluegrass, squirrel-tail and needlegrass. Low sagebrush and stiff sagebrush types are found on poorer sites than big sagebrush. Low sage is common in northeastern California on low-lying, poorly drained sites within the big sagebrush type and as inclusions within ponderosa pine and western juniper types. Stiff sagebrush is common in eastern Oregon and eastern Washington on very shallow, stony soils. Pinyon-juniper type, for the most part, occurs within sagebrush communities, and is considered by some to be part of the sagebrush ecosystem.

Desert shrub ecosystems include about 3.5 million acres in southeastern Oregon and nearly 20 million acres in California, mostly in the southeastern portion. In Oregon, desert shrub types include saltbush, shadscale, and greasewood communities. They occur on saline soils in low-lying areas often intermingled with upland sagebrush communities. Other shrubs present include spiny hopsage, bud sagebrush, and winterfat. Grasses include giant wildrye, alkali saltgrass and Indian ricegrass (Franklin and Dyrness 1973).

In California, desert shrub ecosystems include saltbush, shadscale, creosote bush, blackbush, and Joshua tree woodland communities. Creosote bush is one of the most extensive types in the Mojave Desert. It is found from below sea level in Death Valley to elevations of 5,000 feet elsewhere. Among its many associates are shadscale, saltbush, encelia, Mormon tea, krameria, yucca, prickly pear, and ragweed. Blackbush type is widespread in the desert from about 4,000 feet in elevation up to 6,000 feet. It is found in cooler areas than creosote bush. Generally, blackbush grows where snow occurs for short periods during the winter. Associates include spiny hopsage, Mormon tea, winterfat, shadscale, bud sagebrush, horsebush, yucca, and buckwheat. Joshua tree woodland occurs along the fringes of the pinyon-juniper woodland, and within blackbush and shadscale types (but generally on lighter, less rocky soils). Some of the same associates found in blackbush and shadscale types are found as understory plants in Joshua tree woodland. Other associates include yucca, bladder-sage, haploppapus, galleta, and muhlenbergia. (Barbour and Major 1977).

The productivity of rangelands in California, Oregon, and Washington is extremely variable. Desert ecosystems produce up to 250 pounds of forage per acre on better sites, while grasslands may produce up to 5,000 pounds. Annual grasslands have the highest productivity of any of the extensive types, averaging more than 2,000 pound per acre. The better sites may produce over 3,000 pounds (Garrison et al. 1977).

In California, Oregon, and Washington combined, 51% of the rangeland is owned by the federal government. Ownership distribution varies by state (table 15).

About two-thirds of the federal rangeland is administered by the BLM. In California, nearly 3 million acres are in military reservations. Other federal owners of rangeland include the Forest Service, National Park Service, Corps of Engineers, Bureau of Reclamation, Fish and Wildlife Service, and native Americans. Nonfederal owners include the states and other local governmental agencies, and private individuals and corporations.

The most productive rangelands, and those most manageable in terms of accessibility and physiography, are usually in private ownership. These are the mountain valleys and the highly productive annual grasslands of California. The California desert, the sagebrush types and the high mountain grasslands are in federal ownership.

Rangeland area has decreased during the past 10 years in the three states, but losses have been comparatively light. Little change has occurred in distribution by owner group, but a considerable area of privately owned rangeland has changed owners in the past decade in parts of California. In many areas, pinyon-juniper type has spread into treeless or near-treeless rangeland during the past century, and most noticeably since about 1930. Studies have documented the tremendous water demands of western juniper, and in some areas juniper clearings have resulted in dramatic increases in nearby streamflow. Western juniper and pinyon-juniper have been eradicated in numerous range improvement projects in eastern Oregon and California in the past 20 years. These projects appear to have neutralized the spread of pinyon-juniper type (Bedell 1985).

Range condition has changed dramatically throughout the Pacific Coast states since Europeans first appeared. Misuse and overuse resulted in degradation of rangeland until range conditions reached a low point in the 1930s. In most areas range condition has been improving since then, as government range managers, and ranchers with technical and financial assistance from the Government, have worked to correct the problems created decades to a century before.

The Soil Conservation Service (SCS) evaluates range condition by comparing the present vegetation of a site to the climax vegetation that a given site could support. The climax type is the most stable, therefore the least susceptible to erosion or other degradation (but not necessarily the most desirable for specific uses an owner may desire). For nonfederal rangelands in California, Oregon, and Washington, excluding recently-seeded rangeland and the annual grasslands of California (which are now dominated by introduced plants and cannot be rated by SCS's system), the SCS has rated range condition as follows:

Table 15.—Ownership and percent of rangeland area (million acres) for California, Oregon and Washington, 1987

State	Federal Ownership		Nonfederal Ownership		Total
	Million acres	*Percent*	*Million acres*	*Percent*	*Million acres*
California	18.8	49	19.7	51	38.5
Oregon	12.6	57	9.4	43	22.0
Washington	1.9	25	5.6	75	7.5
Total	33.3	—	34.7	—	68.0

Condition	Percent of rangeland
Excellent (75% + of present community is climax)	6
Good (51 - 75% climax)	21
Fair (26 - 50% climax)	36
Poor (25% and less climax)	37

An evaluation by SCS of the treatment needed on all rangeland in nonfederal ownerships showed that 26% of the rangelands were adequately protected; treatment was not feasible on 15% of the rangelands, because a reasonable economic return was not likely; and conservation treatment was needed on the remaining 59%. Six conservation treatment practices are recommended in California, Oregon, and Washington, on nonfederal lands. They are:

Conservation Treatment	Percent of Nonfederal Rangeland
Protection only	26
Improvement without brush management	19
Improvement with brush management	18
Re-establishment	8
Brush management and re-establishment	10
Erosion control	19

Hawaii

Rangeland area is estimated to total 1.4 million acres in Hawaii. Most of the original native plants on Hawaii's rangelands have been replaced by introduced perennials. The major conservation practices needed are planned grazing systems (intensive grazing management); proper range use; fencing (4,000 miles in 7 years); and providing pipelines, troughs, and tanks (livestock water). Intensive grazing management is being practiced on about 40,000 acres in the state.

WATER AREA

Within the Pacific Coast states are 20.1 million acres of water. Of this, about 1.6 million acres are in coastal waterways such as Puget Sound, Strait of Juan de Fuca, and San Francisco Bay (Alaska's coastal waterways are excluded). Inland water makes up the remaining 18.6 million acres, about 87% of which is in large bodies of water (lakes at least 40 acres in size and streams at least 1/8-mile wide). Numerous natural and artificial bodies of water are included: Lake Tahoe; Crater Lake; Lake Roosevelt, created by Grand Coulee Dam; and a long list of rivers, including the Columbia and Yukon, and many lesser rivers such as the Sacramento, San Joaquin, Willamette, Umqua, and Rogue. The remaining 13% of inland water is made up of lakes and ponds between 2 and 40 acres in size and streams between 120 feet wide and 1/8-mile wide. In this category are numerous tributary streams such as California's Feather and Mokelumne Rivers; Oregon's Deschutes, John Day, and McKenzie Rivers; and Washington's Okanogan, Nisqually, and Puyallup Rivers.

More than 80% of the total area of inland water in the Pacific Coast Section is in Alaska. Besides the numerous large rivers such as the Yukon system, more than 3 million lakes over 20 acres in size are scattered through the state.

CHAPTER 6: OTHER RESOURCES OF THE LAND BASE

MINERALS AS FOREST AND RANGELAND RESOURCES

Minerals are significant forest and rangeland resources, and most mining takes place on forest and rangelands. In part, this is because area in forests and rangelands is larger than in any other land use category. Further, the mountainous topography and high elevations (with harsh weather), where much of the mining occurs, have deterred other uses and made the lands most suitable for forest and range. Because minerals lie beneath the land's surface, development of mineral resources affects management of surface resources. Likewise, reservations of land for specific surface uses and values affect the availability of subsurface minerals.

There are some 2,500 minerals, broadly defined as any material from the earth that might be used in home or industry (Wenner 1984). About 100 of these substances are of worldwide economic importance.

For purposes of analysis, minerals can be placed in three broad categories:

- Energy minerals, including oil, coal, oil shale, tar sands, uranium, and geothermal resources.
- Metallic minerals such as iron, aluminum, chromium, cobalt, molybdenum, copper, lead, gold and silver.
- Non-metallic minerals and mineral materials, including common construction materials such as sand and gravel; fertilizer corundum; chemical minerals such as arsenic and salt; and gems like diamonds and emeralds used in jewelry and some industrial processes.

Unlike renewable resources that can be subject to rather precise inventory or, in the case of timber, calculation of growth rates with reasonable accuracy, there is considerable uncertainty about the extent of the Nation's minerals resources.

Energy Minerals

There is disagreement among experts over the extent of the Nation's reserves of petroleum, and supplies are uncertain over the long term. It appears that most of the easily-recoverable supplies of petroleum have been depleted; oil fields in the contiguous 48 states have been pumped for many years, and recovery rates are declining (Abelson 1987; Fisher 1987). The average output of domestic wells in 1984 was 14 barrels a day, compared to 12,011 in Saudi Arabia (Abelson 1987). According to the U.S. Department of Energy, the United States in 1985 had proven reserves of 28.4 billion barrels of crude oil (about a 9-year supply at current production rates), and an estimated 82.6 billion barrels of undiscovered recoverable crude oil (U.S. Department of Energy 1987).

However, other experts contend that there are 300 billion barrels of oil that could be recovered, although it would require expensive new technology (Abelson 1987; Fisher 1987). In fact, the U.S. continually adds to its reserves through technology that makes oil economically recoverable, enlargement of proven reserves, and new discoveries. The 9-year reserves-to-production ratio has held at that level or higher for more than three decades (U.S. Department of Energy 1987).

The United States also has substantial amounts of natural gas. A 1988 study for the Department of Energy estimated that technically recoverable natural gas in the U.S. reserve and resource base amounted to 1,188 trillion cubic feet (Argonne National Laboratory 1988). This figure includes 1,059 trillion cubic feet beneath the 48 contiguous states, and another 129 trillion cubic feet in Alaska. Of the 1,059 trillion cubic feet of natural gas deemed to be technically recoverable in the lower 48 states, more than half—583 trillion cubic feet—is judged to be economically recoverable at a wellhead cost of less than $3 (1987 dollars), including finding costs, per million cubic feet. If this is the case, the U.S. has, at current levels of consumption, a 35 year supply of natural gas at a cost equal to or below $3 per million cubic feet (Argonne National Laboratory 1988).

The United States has abundant supplies of coal, with reserves estimated to be 478.2 billion short tons (U.S. Department of Energy 1985). The U.S. now consumes less than a billion tons of coal per year. Coal can substitute for oil for power generation and some heating uses. Some authorities foresee significantly increased use of coal as domestic oil becomes more expensive to develop (Lansberg 1987). However, there are serious environmental concerns—notably acid deposition—associated with its use which need to be overcome if coal is to realize its potential. The United States also has large reserves of oil shale, with estimates ranging from the equivalent of several hundred billion barrels of oil to more than a trillion barrels (Abelson 1987).

The nation also has large amounts of uranium, if required for power generation, and the potential for increased use of geothermal resources (U.S. Department of Energy 1985).

Metallic Minerals and Precious Metals

Overall, the Nation has large quantities of many metallic minerals. In 1986 it was among the world's top producers of 33 of the 87 minerals monitored by the U.S. Department of Interior's Bureau of Mines, and a major producer of a number of others (U.S. Department of Interior, Bureau of Mines 1985). For example, the domestic reserve base (identified resources which may reasonably

become economic to exploit) of copper amounts to 90 million tons, enough to last 47 years at 1985 consumption rates. The domestic reserve base of lead amounts to a 23-year supply. The reserve base of gold would last 39 years; silver, 14 years; and molybdenum, 353 years (Department of Interior, Bureau of Mines 1987b).

However, relatively little is known about the actual extent of the Nation's minerals reserves. Moreover, their use is influenced by accessibility; cost of exploration, development, and production; and by the availability of technology that permits their extraction in an environmentally-sound manner at competitive cost. Most of the minerals available in the United States are available in other countries as well. The world price of a mineral affects the competitive position of domestic producers. For example, while the United States has substantial reserves of copper, in 1987 it imported about half of the copper consumed domestically because it was cheaper to buy it overseas than to exploit domestic sources (U.S. Department of Interior, Bureau of Mines 1987a).

Some minerals are in short supply domestically or deposits are of such low quality that they cannot be produced economically; thus the United States relies almost exclusively on foreign sources. Some minerals are of great economic and strategic importance (Hargreaves and Fromson 1983). For example, the U.S. imports 100% of the manganese and columbium (both used to increase the hardness and durability of steel) it consumes, 94% of the cobalt, 92% of platinum-group metals, and 92% of industrial diamonds (U.S. Department of Interior, Bureau of Mines 1987a). For some of these minerals, potential economic and political instability of the source countries raises questions of supply security (Hargreaves and Fromson 1983).

The Nation's reserves of metallic minerals, like energy minerals, are not static; changes in world prices or more efficient mining and processing technologies could make current uneconomic reserves profitable to develop or stimulate a search for new reserves. Also, ores predominantly of one mineral often contain another mineral that can be economically produced as a byproduct or co-product. For example, cadmium is produced as a byproduct of zinc (Hargreaves and Fromson 1983).

Non-Metallic Minerals and Minerals Materials

Nationwide, supplies of minerals materials used in construction, such as sand, gravel, stone, and clay, are virtually inexhaustible (U.S. Department of Interior, Bureau of Mines 1985). However, because of their weight and bulk, transportation is costly and as a practical matter, they are usually produced near where they are to be used. There are areas where some important construction materials, such as sand and gravel, occur in limited amounts or are nonexistent and local shortages do occur. In areas where supplies of mineral materials exist, land use and environmental constraints are major factors limiting development (U.S. Department of Interior, Bureau of Mines 1985). The nation possesses significant reserves of fertilizer minerals; however, there are concerns over the environmental impacts of phosphate mining in Florida, where most U.S. phosphate is produced.

Location of Minerals

The areas of highest mineralization are the mountains and basins of the West and the Appalachian chain in the East. However, minerals of economic importance are widely scattered throughout the United States. For example, there are identified iron deposits in all but six states.

Coal underlies about 13% of the Nation and occurs in 37 states (U.S. Department of Agriculture, Forest Service, 1979). The bulk of the Nation's coal reserves, however, are located beneath the Allegheny Plateau and the Cumberland Plateau in the East, the Ohio and Mississippi River Valleys and the Great Plains (U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement 1987). Oil deposits are concentrated in an area extending from Oklahoma south to central Texas, with scattered deposits beneath the eastern plateaus and western basins (U.S. Department of Energy 1985). Geothermal resources occur mainly in the West, although there are areas of geothermal activity in the Appalachians and along the Atlantic Coast. (Honig et al. 1981).

Although deposits of individual metallic minerals may be found in many areas of the Nation, production is typically far more limited. For example, although there are deposits of copper throughout the Appalachian Mountains, Missouri, Oklahoma, Michigan, Minnesota and all the western contiguous states, only six states (Arizona, Michigan, Montana, Nevada, New Mexico, and Utah) produce significant amounts of copper, and the bulk of U.S. production comes from Arizona and Utah. Beryllium is produced at a single mine in Utah, although there are deposits in Alaska and Texas as well (Bureau of Mines 1987a).

Ownership of Minerals

There is little information on the quantities of minerals in public and private ownership. In part this is because relatively little is known about what mineral deposits actually exist. Further, no agency maintains statistics on the ownership of known deposits. The ownership of metallic minerals is extremely complex and often transitory. For example, those minerals deemed locatable under the Mining Law of 1872 (generally, metallic minerals and uranium on public lands in the 11 contiguous western states and Alaska) on federal lands become private property with their discovery and the filing of necessary legal papers (Leshy 1987). The key question is not one of who owns the minerals, but whether they are accessible and available for development, and under what conditions.

Somewhat more is known about the federal government's ownership of energy minerals, since these minerals are subject to lease. In the West, the federal government owns about 60% of the 234 billion tons of identified coal reserves (U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement 1987). In the East, where there is relatively little public land, the majority of coal is privately owned. About 6.5 million acres of the 191 million-acre National Forest System is known to be underlain by coal. Another 45 million acres is believed to have oil and gas potential, and 300,000 acres have potential for oil shale (U.S. Department of Agriculture Forest Service 1985).

Mining on Forest and Rangelands

There is relatively little information specific to mining on forest and rangelands, public or private. There are some national data, although now nearly 10 years old, on land used for mining. Since most mining takes place on forest and rangelands, it provides generalized information on the extent of mineral development on these lands. In addition, federal agencies maintain information on various aspects of mineral development, such as mining permits issued, acreage under permit, and sales and leases on federal lands. Collectively, they provide a picture, though fragmentary, of the extent of mining on the Nation's forest and rangelands.

Mining occurs on only a small fraction of the Nation's land. Between 1930 and 1980, about 5.7 million acres had been used for mining for all types of minerals[4] (Johnson and Paone 1982.) This amounts to about one-quarter of one percent of the Nation's land, an area about equal to the State of New Hampshire. By contrast, some 27 million acres are devoted to highways, rural roads, railroad rights-of-way, and airports (Frey and Hexem 1985). With regard to the long-term pre-emption of other uses, the effect of some kinds of mining is not as severe as the conversion of forest and rangeland to urban development, where there is little probability that the land ever will be returned to forest or range.

Even though it involves a small area compared to the Nation's total area, mining activity can have a disproportionate impact on some areas. For example, six states—Pennsylvania, Kentucky, West Virginia, Ohio, Illinois, and Indiana—accounted for nearly half of all the land used for mining between 1930 and 1980 (Johnson and Paone 1982). During the period more than 1% of the land area of each state was mined, and three states (Pennsylvania, Kentucky, and West Virginia) had more than 2% of their land used for minerals extraction (table 16). In each of these six states plus California and Florida, mining used more than 250,000 acres. Within states, some areas are intensely affected. Of the 121,820 acres used for mining in Arizona, 91,200 acres were in the state's copper region. Similarly, 90,000 acres have been mined in northern Minnesota's Mesabi Iron Range (Johnson and Paone 1982).

According to the Department of Interior, Bureau of Land Management (1987), about 732 million acres of federal land are subject to surface and subsurface mineral-development, the majority of it in the West and Alaska. As of September 30, 1986, nearly 95 million acres were under lease for oil and gas, just over 2 million acres had been leased for geothermal development, and another 1.3 million acres had been leased for coal. While the minerals under this land are subject to extraction, it does not mean that all the surface will be disturbed as a result of development. Data on leases for some important minerals on federal land are shown in table 17.

[4]*Area includes area of surface mine excavation, area used for disposal of surface mined waste, surface area subsided or disturbed as a result of underground workings, surface area used for disposal of underground workings. and surface area used for disposal of mill or processing wasted. It does not include land used for haulroads, fresh water reservoirs, railroads and public highways to edge of mining properties, or streams affected by acid drainage and sedimentation (Johnson and Paone 1982)*

Table 16.—States leading in amount of land used for mining 1930-1985, by total land area, acres mined, and percent of total area

State	Total land area	Acres mined	Percent of total
	Thousand acres	*Acres*	
Pennsylvania	28,805	635,530	2.21
Kentucky	25,512	533,410	2.09
West Virginia	15,411	318,120	2.06
Ohio	26,222	507,320	1.93
Indiana	23,158	260,660	1.13
Illinois	35,795	411,380	1.11

Source: Johnson and Paone 1982.

While there are no figures on acreage being mined on the national forests, data on national forest minerals production confirm that significant amounts of some important minerals are extracted from the national forests (table 18). In 1986, the national forests were major contributors to the Nation's production of molybdenum (69% of national production), lead (63%), gold (15.1%), silver (13%), copper (6%), and phosphate (5%). In terms of energy minerals, the national forests in 1986 produced 11.4% of the Nation's output of uranium and 4.6% of its coal, but only 1.2% of the natural gas and .00059% of the oil produced domestically.

Reclamation of Mined Lands

Once the mineral deposit has been removed, the land can be reclaimed and returned to other uses. A 1982 study of land used for mining of all types between 1930 and 1980 estimated that some 2.7 million acres, or 47% of the 5.7 million acres of land disturbed had been reclaimed by industry (Johnson and Paone 1982). The Surface Mining Control and Reclamation Act (SMCRA) requires reclamation of land disturbed for coal mining; thus it is presumed that all land mined since 1977 has been or will be adequately reclaimed. Since 1977, more than 10,000 abandoned mine sites (primarily coal), and nearly 65,000 acres have been treated through the Abandoned Mined Land Program established by SMCRA (St. Aubin and Massie 1987).

It is difficult, however, to determine the pace of reclamation of abandoned coal mines, the extent of reclamation of non-coal mines, or the adequacy of reclamation efforts under SMCRA. Johnson and Paone (1982) cite a 1979 Bureau of Mines report indicating that about one million acres of coal lands mined between 1930 and 1971 "remained in an abandoned state." If that estimate was reasonably accurate, less than 10% of abandoned lands have been treated under the Abandoned Mined Land Program. Some private groups have been critical of the implementation of SMCRA, claiming that enforcement of the law's provisions by the Office of Surface Mining Reclamation and Enforcement have been lax and haphazard (Dunlap and Lyon 1986). The General Accounting Office (GAO) also noted difficulties in reclaiming surface mined land on which operators had forfeited

Table 17.—Minerals leases, licenses, permits and application on federal land for selected energy and non-energy minerals

Mineral	Leases in effect as of Sept. 30, 1986		Leases issued in FY 1986	
	Number	*Thousand acres*	*Number*	*Thousand acres*
Oil and gas	102,885	92,729.9	9,009	9,927.4
Geothermal	1,212	2,039.1	144	242.6
Coal Leases	1,190	1,353.9	13	20.7
Licenses permits & applications	278	438.6	5	1.5
Uranium[1]	131	34.1	1	.8
Phosphate[1]	307	207.3	---	---
Lead	193	110.5	10	6.7

[1]*Includes all leases, lease applications, and prospecting permits.*
Source: Derived from tables 36-40 in U.S. Department of Interior, Bureau of Land Management. 1987.

Table 18.—Estimated production of selected minerals on national forest land for 1986 compared to total national production

Mineral	Units	Production on National Forest Land	Total domestic production	Percent of production on National Forest Land
Crude oil	M barrels	18,917	3,168,252,000	([1])
Natural gas	MM cu f	189,663	15,991,000	1.19
Coal	M sh tons	41,221	890,315	4.63
Uranium	MM lbs	1.50	13.20	11.36
Geothermal	Kilowatts	17,677	1,580,000	1.1
Lead	metric tons	223,455	353,115	63.28
Phosphate	M metric tons	1,814.91	38,700	4.69
Copper	metric tons	93,995.102	1,479,432	6.35
Molybdenum	M lbs.	65,275	3,976	69.46
Gold	M troy oz	563.80	3,733	15.10
Silver	MM troy oz	4,455.84	34,200	13.03
Limestone	M sh tons	1.83392	767,250,000	([1])
Sand & gravel	MM sh tons	13.22350	88	31.5

[1]*Less than 0.5 percent.*
Source: U.S. Department of Agriculture, Forest Service, Minerals and Geology Management Staff 1988; and U.S. Department of the Interior, Bureau of Mines 1986.

performance bonds in Pennsylvania and West Virginia (General Accounting Office 1986).

Effects of Mining on Surface Resources

Mining can have a significant effect on surface resources. However, the effects are highly variable depending on the mining method, the mineral, the processing technology used, and the ecological nature of the site. Potential impacts include preemption of land for other uses, destruction or impairment of fragile ecosystems and wildlife habitats, contamination of surface and subsurface water supplies and soils from toxic chemicals and radioactivity, and adverse effects on scenic values (National Research Council 1979, Council on Environmental Quality 1981). Although effects are most apparent while the mine is active, some effects—such as pollution of water from waste seepage, or large areas of waste tailings—can persist long after mining has been discontinued. While most of the adverse ecological affects can be prevented or mitigated through care and thorough reclamation, a 1987 report by the Environmental Protection Agency placed mining in the second of six ranked categories of ecological risk, behind ozone depletion and atmospheric CO_2 and global warming, and equal in risk to the physical alteration of aquatic habitats (U.S. Environmental Protection Agency 1987).

Mining preempts most surface uses, but the reverse is also true. Surface use or the designation of special management regimes to protect surface uses or values can effectively preclude or prohibit mineral development. The development of an urban shopping mall effectively prevents the development of whatever mineral resources may lie beneath it. The development of a forest campground or visitor center makes development of

mineral resources doubtful. Statutes have explicitly limited mining on forest and rangelands. Under provisions of the National Wilderness Preservation Act, no mineral exploration has been permitted in national forest wilderness areas since 1984. The Surface Mining Control and Reclamation Act prohibits surface mining for coal on the national forests. The forest land management plans being prepared by individual national forests are likely to further constrain exploration and development of leasable minerals. It is not known how much of the Nation's forest and rangelands is precluded from mining because of statute, administrative fiat, or private landowner objectives, but it is substantial.

THE NATION'S WETLANDS

Wetlands include marshes, swamps, bogs, small ponds, sloughs, potholes, river overflows, oxbows, mud flats, and wet meadows. They are generally lands where saturation with water is a dominant factor that determines the nature of soil development and the types of plant and animal communities that live in the soil and on the surface. They are transition lands between terrestrial and aquatic systems where the water table is usually at or near the soil surface or the land is covered at least part of the year by shallow water. These lands deserve special attention because this portion of the Nation's forest and rangeland base has high biological productivity and is important as habitat for wildlife and fish at critical times in their life cycle.

Estimates of the original wetland acreage present in the United States at the time of settlement vary, however, a reliable account places the extent at 215 million acres for the conterminous United States (Roe and Ayres 1954). In 1906, the U.S. Department of Agriculture conducted one of the first wetlands inventories and estimated the total at 127 million acres (Shaw and Fredine 1971). Estimates for the mid-1970s place the total at about 99 million acres (Frayer et al. 1983). These inventories have shown conclusively that wetland acreages are declining. Thus, today's wetland resource in the United States probably represents less than 46% of our original wetlands and 78% of those present at the turn of the century.

The U.S. Fish and Wildlife Service classifies wetlands and deepwater habitats into five ecological systems (Cowardin et al. 1979). The most important from the perspective of forest and rangeland, the Palustrine System, encompasses the vast majority of inland marshes, bogs, and swamps. The palustrine forested wetlands occur mostly in the eastern United States and Alaska. In the East, they are the most abundant wetland type. They include black spruce bogs, cedar swamps, red maple swamps, and the bottomland hardwood forests that dominate our major river systems. In the mid-1970s, of the 94 million acres of palustrine wetlands present in the conterminous United States, nearly 50 million acres were forested.

The Nation's wetlands are mostly privately owned. The U.S. Fish and Wildlife Service estimates that there were approximately 95 million acres of wetlands in the United States in 1985 (U.S. Department of Interior, Fish and Wildlife Service 1988). Of this total, about 70 million acres of the wetlands were in private ownership, 12 million acres were administered by federal agencies, and the remainder was owned or administered by other public agencies.

An indication of the trend in wetland gains and losses is documented in the U.S. Fish and Wildlife Service report that deals with the 20-year period between the mid-1950s and the mid-1970s (Tiner 1984). During this period, wetland flats increased 200,000 acres, and about 2.1 million acres of ponds and reservoirs were created. Pond acreage nearly doubled from 2.3 million acres to 4.4 million acres, primarily due to farm pond construction in the central part of the United States. Most of the pond acreage came from former upland pastures, although 145,500 acres was forested. Despite the gains in wetlands from new ponds and reservoirs, beaver activity, and irrigation and marsh creation projects, the losses of wetlands during the period were enormous. Eleven million acres were destroyed, but the net loss was reduced to 9 million acres because of the 2 million acres of newly created wetlands. Agricultural development involving drainage was responsible for 87% of the national wetland losses and urban and other development was responsible for the remaining 13%.

Agriculture had the greatest impact on forested wetlands, accounting for a loss of 5.8 million acres. Greatest losses took place in the Lower Mississippi Valley with the conversion of bottomland hardwood forests to cropland. Shrub wetlands were hardest hit in North Carolina where many pocosin wetlands were converted to cropland and pine plantations or were mined for peat. Inland marsh drainage for range and agriculture was most significant in the prairies of the Dakotas and Minnesota, the sandhills of Nebraska, and in the Florida everglades.

SOIL PRODUCTIVITY AND MANAGEMENT

Land uses and resource outputs are influenced to a considerable degree by soils. The quality and quantity of range, recreation, timber, water, wilderness, and wildlife resources are directly related to the inherent productivity and the existing condition of the soil resource. Often this relationship is incompletely understood, but typically, high inherent soil productivity and favorable existing soil conditions result in more flexible management opportunities and increased resource outputs.

Soil characteristics and soil management concerns may vary greatly over short distances, yet broad regional trends can be recognized. Figure 21 displays three major soil management concerns: land mass failure hazard (landslides), severe surface erosion hazard, and high water tables. The circles within each section represent total National Forest System (NFS) acres, with the relative portions representing lands identified with one of the three major soil management concerns. The discussion that follows concerns NFS lands; but parallels can be drawn for forest and rangeland of other owners in the same section of the country.

The total NFS land area affected by major soil management concerns ranges from about 25% in the Rocky Mountains and Great Plains Sections to slightly less than 50% in the South Section. Severe surface erosion hazard

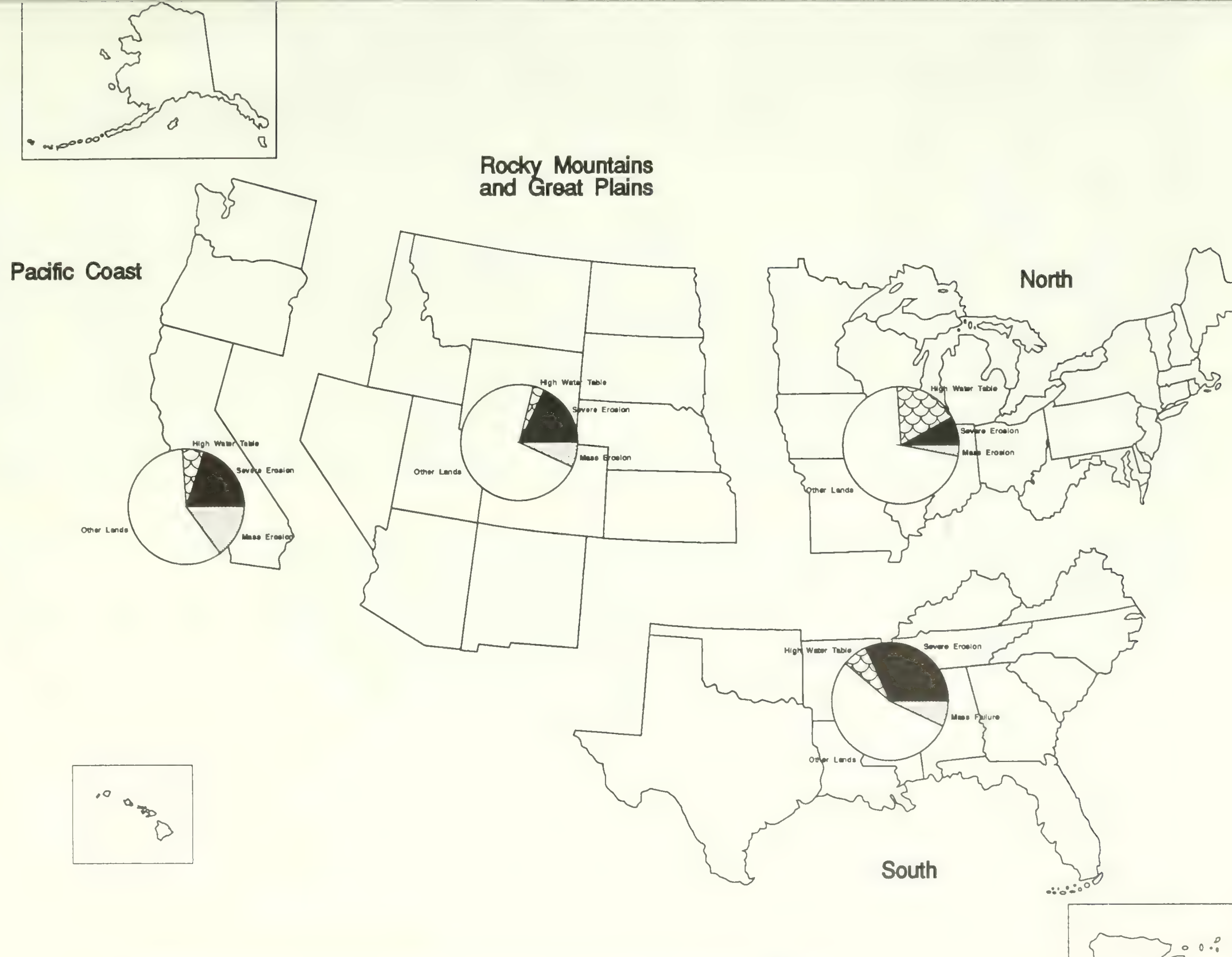


Figure 21.—Extent of major soils management concerns related to soil productivity on NFS lands.

is identified as the leading major soil management concern in all but the North Section. A total of 33,784,000 acres of NFS land nationally have severe surface erosion hazards. Land mass failure hazards are a significant concern in the South and Pacific Coast Sections, primarily due to high rainfall rates and high soil moisture content. A total of 17,756,000 acres of NFS land nationally have high land mass failure hazards. High water tables are the major soil management concern in the North Section, and are associated with a relatively large percentage of organic (peat and muck) soils. Nationally, a total of 8,856,000 acres of NFS land are identified with high water tables that limit management.

Management concerns and soil productivity for lands with high water table vary significantly by Section. While high water table soils often have unique management opportunities, in general, management activities are restricted by low soil strength. Managers in the North Section, with the greatest identified concern, can schedule ground-disturbing activities in winter, when the ground is frozen and the potential for detrimental soil disturbance is least. Frozen soil conditions rarely exist in the South Section; thus ground-disturbing activities are restricted to dryer seasons with increased use of specialized equipment. High water tables in the Rocky Mountain and Great Plains Sections are generally associated with stream courses. Management concerns often relate to location of roads and their effect on riparian values. The majority of limiting high water table soils in the Pacific Coast Section are located in Alaska. The relative productivity of high water table soils is low compared to upland soils in the North and Pacific Coast Sections but high in the South Section. However, the highest rangeland soil productivity values are associated with high water table soils in the Rocky Mountains and Great Plains Sections.

Surface erosion hazards affect land management in different degrees based on vegetation type and past management history. Much of the NFS land in the South Section was previously privately owned, cleared for crop production, and then abandoned before being acquired by the Government. At the time of acquisition, soil conditions were deteriorated and accelerated erosion was common. Subsequent reforestation has eliminated much of the accelerated erosion and has reversed the trend in loss of inherent soil productivity, but the high erosion potential still exists. Severe surface erosion hazards in the Rocky Mountains and Great Plains Sections are generally associated with arid rangelands where vegetative ground cover is naturally sparse. In the Pacific Coast Section, severe erosion conditions are concentrated on the arid brush lands of California. Surface soil erosion is generally not a problem on forest lands, unless extensive ground disturbance occurs.

Land mass failure hazards affect management by reducing access to an area. Often lands with these hazards have high inherent soil productivity. Landslides in the Pacific Coast Section, on steep, moist, forested slopes, can be initiated by removal of the forest vegetation. Removal of the forest canopy, with the corresponding decrease in water transpiration by trees, often increases soil moisture content and triggers land mass failures. Hazards are often difficult to identify and evaluate in the Pacific Coast Section because of the dense forest cover. In the Rocky Mountains and Great Plains Section, land mass failure hazards are more easily identified due to the drier nature of the surrounding landscapes. Often hazard areas occupy narrow corridors or lower slope positions used for roads. In the Appalachian Mountains of the South Section, severe surface erosion hazard areas and land mass failure areas exist in close proximity.

Nationwide, about 27 million acres of NFS forest land are identified as having a high potential for soil productivity enhancement—primarily from fertilization. Also included are rangeland soils that could be improved by such practices as pitting, furrowing, and ripping.

Detrimental soil compaction and its effect on long-term soil productivity is a concern on intensively managed forest lands. On certain soils, use of mechanized equipment substantially reduces soil porosity and infiltration, which lowers productivity. The degree of impact is affected by many factors, including the type of equipment used, duration of use, soil moisture content, and existing soil condition. Detrimental soil compaction is a significant concern in the Pacific Coast and South Sections.

While broad sectional differences for soil management concerns can be identified, soil capability and productivity may vary greatly over extremely short distances. Identification of specific soil properties, combined with an understanding of basic biotic and soil processes, fosters effective resource management. The number of acres of national forest land that still need to be surveyed (called soil resource inventory needs) is shown in table 19.

Table 19.—Soil resource inventory needs (million acres) on national forest lands by section and vegetation type

Vegetation Type	Sections				
	All sections	North	South	Pacific Coast	Rocky Mountains and Great Plains
Hardwoods	0.8	0	0.4	0	0.4
Softwoods	47.2	6.1	6.8	12.2	22.1
Range/Alpine/Shrub/Muskeg	21.9	0.7	0.8	1.7	18.7
Total	69.9	6.8	8.0	13.9	41.2

Source: Nordin 1987.

CHAPTER 7: PROJECTING LAND COVER AND USE CHANGES

This chapter provides projections of changes in area for the forest and rangeland base. Area changes of the land base are important not only in terms of prospective supplies of timber, water, wildlife, and forage, but also for the intangibles such as scenery and opportunities for outdoor recreation.

Projected area changes for the resource base are described first with a national overview and then for the five major geographic sections: the North, Great Plains, South, Rocky Mountains, and the Pacific Coast. Components of the resource base—forest land, rangeland, and water areas—are the three major categories covered. Projections of area changes at the national level are the sum of regional projections from region-specific systems for projecting area change. Methods for projecting area change are discussed in more detail in Appendix A (Alig et al. 1989).

NATIONAL OVERVIEW

Available data indicate that the area in forest and range land has been declining in recent decades (Table 20). The inland water area, on the other hand, has been increasing mainly due to reservoir construction. The relative intensity of forces affecting competition for land resources among major uses in the United States has changed notably since the last RPA Assessment in 1979. Many acres of forests and rangelands were converted to crop agriculture in the late 1970s and early 1980s, due in large part to rapid growth in agricultural exports. As with the rest of the economy, the allocation of domestic land resources is increasingly being influenced by international trade and economic conditions.

In 1950, agricultural products from about one-seventh of the cropland harvested (50 million acres) went for exports. In 1980, this had more than doubled to one-third of the harvested crop area, about 133 million acres (Raup 1980). In particular, export-driven demand for crops such as soybeans led to conversion of many acres of bottomland forest. However, the current outlook for U.S. agriculture is uncertain. Area of cropland harvested has dropped in recent years (figure 22) and recent surveys by Forest Inventory and Analysis units indicate accompanying modest gains in forest area in some states. Significant excess capacity in crop agriculture is projected, and along with related government farm programs designed to reduce cropping of highly erodible lands, this will likely reduce land use pressures on the forest and range land base (USDA Soil Conservation Service 1987).

In addition to the land use pressures exerted by crop agriculture on the forest and range land base, conversions pressures from urban and developed uses are substantial. Given recent trends and the essentially irreversibility of such conversions, the future direction of area trends in urban and developed uses appears more evident than those for agricultural uses. Studies suggest that the area in urban and developed uses will continue to grow in line with projected changes in population, personal income, and related factors (Alig and Healy 1987). The population of the U.S. is projected to increase by more than 90 million people by the year 2040, representing an increase of close to 40% (USDA Forest Service 1987).

Along with the population increase, per capita disposable personal income is projected to much more than double in constant dollar terms by 2040. Such changes will continue to fuel the expansion of urban and developed uses, and may be compounded by the overall aging of the U.S. population over the next several decades. The trend in rural versus urban growth in the 1970s and early 1980s may be changing in the latter half of the 1980s. This has important land use implications because of the differential in per capita land consumption between rural and urban uses (Alig and Healy 1987).

The total area of forest and range land is projected to increase about 2% between 1987 and 2000, and then decrease slightly by 2040. The projected increase in the forest and rangeland base by 2000 results from a 6% increase in rangeland, from 770 to 809 million acres (table 20). Between 2000 and 2040, the trend in range area is projected to be stable at around 810 million acres. The area of forest land is projected to decline over the projection period, decreasing by 4% by 2040, from 731 to 703 million acres.

The projected reduction in forest land area (table 21) will result mainly from conversion to other land uses,

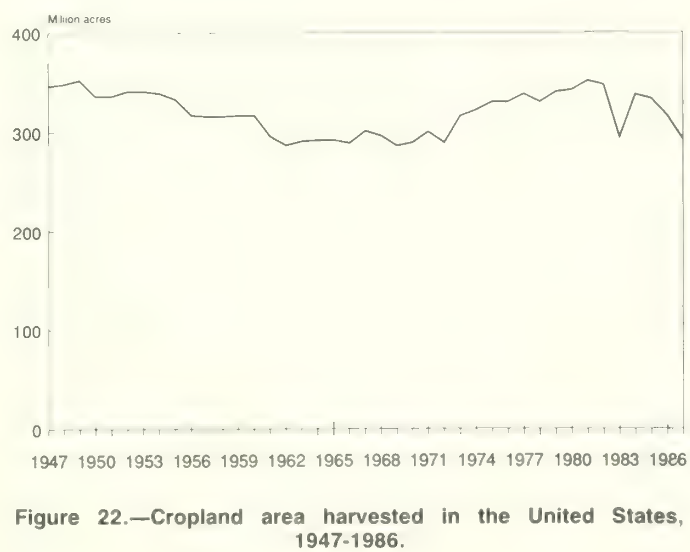


Figure 22.—Cropland area harvested in the United States, 1947-1986.

Table 20.—Land and water areas (million acres) of the United States, by class of land and water, 1970, 1977, and 1987, with projections to 2040

Class	1970	1977	1987	Projections 2000	2010	2020	2030	2040
Land:								
Forest and range land:								
Forest land[1]	754	737	731	718	714	710	706	703
Rangeland[2]	819	820	770	809	809	809	810	810
Total	1,573	1,557	1,502	1,527	1,523	1,519	1,516	1,513
Other land[3]	687	699	756	728	730	732	733	735
Total	2,260	2,257	2,258	2,255	2,253	2,251	2,249	2,248
Water[4]	105	107	107	110	112	114	116	117
Total	2,365	2,365	2,365	2,365	2,365	2,365	2,365	2,365

[1]*Land at least 10% stocked by forest trees of any size, or formerly having such cover, and not currently developed for nontimber use. Included in these lands are transition zones, such as areas between heavily forested and nonforested lands and forest areas adjacent to urban and built-up lands, which may not have timber production as a primary use.*

[2]*Land on which the natural vegetation is predominately grasses, grasslike plants, forbs, or shrubs; and which is not currently developed for nonrange use.*

[3]*Other land includes cropland, improved pasture, industrial and urban land, and all other land categories except forest land and rangeland.*

[4]*Water area includes lakes and ponds over 2 acres in size, waterways, the Great Lakes and coastal waters and estuaries excluding Alaska and Hawaii.*

Table 21.—Forest land area (million acres) in the U.S. by section, 1977, and 1987, with projections to 2040

Section	1977	1987	Projections 2000	2010	2020	2030	2040
North and Great Plains	167	170	168	167	166	165	165
South	209	203	198	197	195	194	193
Rocky Mountains	137	138	135	134	134	134	134
Pacific Coast[1]	224	220	217	216	214	213	211
U.S. Total	737	731	718	714	710	706	703

[1]*Includes Alaska and Hawaii.*

Table 22.—Rangeland area (million acres) in the U.S. by section, 1977, and 1987, with projections to 2040

Section	1977	1987	Projections 2000	2010	2020	2030	2040
North and Great Plains	78	75	91	90	89	88	86
South	123	116	128	128	129	130	130
Rocky Mountains	332	339	349	349	350	350	350
Pacific Coast[1]	256	241	241	242	242	243	244
U.S. Total	789	771	809	810	810	811	810

[1]*Includes Alaska and Hawaii.*

such as reservoirs, urban expansion (figure 23), highway and airport construction, and surface mining. Increased reclamation of mined lands in the future will limit the long run impacts of surface mining on the total area of forest and range land (see previous section).

The projected average annual reduction in U.S. forest area from 1987 to 2040, about 500,000 acres, is less than that for the period 1970 to 1987, which averaged approximately 1.5 million acres per year. These projections represent net area changes, and significant shifts among the uses of land at the aggregate level or more local level may underlie the small net area changes in particular uses (Healy and Short 1981).

Additions to forest land will result from tree plantings under the Conservation Reserve Program (CRP) of the 1985 Farm Bill (Moulton and Dicks 1987), which is projected to be the Nation's largest tree planting program in history. Tree plantings and reversions of CRP grassland to forest, due to natural succession, may contribute 5 to 10 million acres of forest land nationwide by the year 2000. Tree plantings established under an earlier related program, the Soil Bank Program of the late 1950s and early 1960s, were largely retained through the first timber rotation (Alig et al. 1980). However, such additions under the CRP and other federal and state programs are projected not to be substantial enough in acreage terms to offset conversions of forest land to urban and developed uses, and conversions of forest land to agricultural land to replace agricultural land that is developed.

The projected 5% increase in rangeland area by 2040 (table 22) will occur largely on private lands. Projections in rangeland area are based on related projected reductions in cropland area by the USDA Soil Conservation Service (1987) to reflect large excess capacity in crop agriculture in some regions and impacts of associated government programs. The largest area increases in rangeland occur by 2000 and are projected for the Rocky

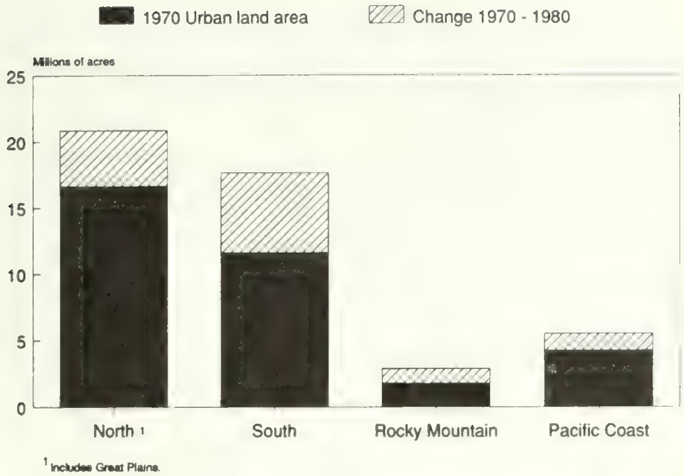


Figure 23.—Urban land area in 1970 and 1980, by region.

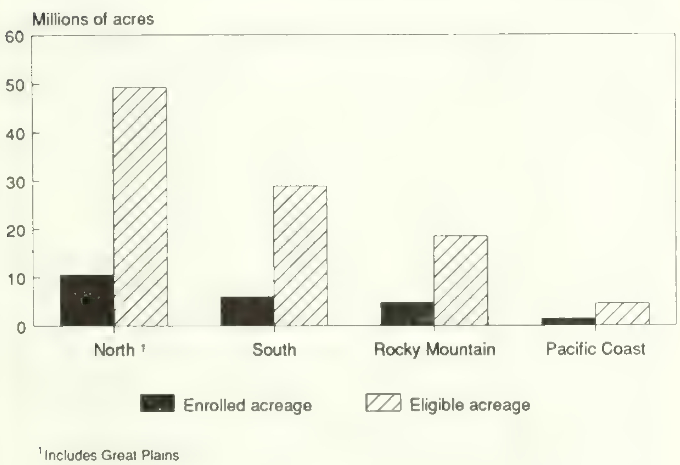


Figure 24.—Conservation reserve program acreage by region, 1986-1987.

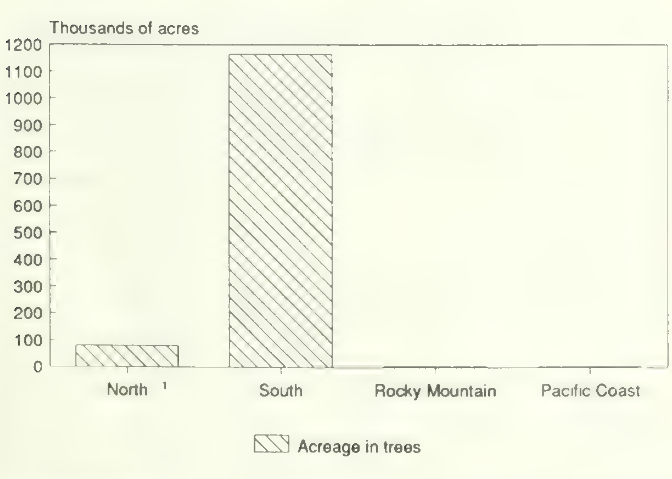


Figure 25.—Conservation reserve program acreage of trees, 1986-1987.

Mountain States, Great Plains, and Southern Plains (Texas and Oklahoma). Projected range area changes in other regions are small. The projected net gain in range area is primarily due to a reduced rate of conversion to cropland and projected acreage additions from natural reversions, due to natural succession, of grassland established under the CRP (figs. 24, 25).

Part of the uncertainty associated with the projections of land use pertain to the implementation of provisions of the 1985 Farm Bill and future farm bills. Three major provisions of the 1985 Farm Bill will likely impact future forest and range area: 1) the CRP, 2) swampbuster and sodbuster provisions, and 3) the conservation compliance provision (Moulton and Dicks 1987).

Approximately 40 to 45 million acres of highly erodible land used currently for cropland are projected to be converted to grass cover or trees under the CRP by the year 2000 (USDA 1989). A large majority of the acres likely to be converted to grass cover are in the South, Great Plains, and Intermountain West. Many of these acres initially seeded to grass will gradually revert to rangeland because of natural succession.

Most southern states have substantial acreages of this highly erodible land suitable for forestation and it is assumed that over 4 million acres would be planted to trees under the CRP by the year 2000. A large majority of the trees planted under the CRP in the U.S. is expected to be in the South (figure 25).

Compared to the CRP, impacts of the "buster" and compliance provisions of the 1985 Farm Bill are more difficult to project in terms of influencing future changes in land use areas. One reason is possible changes in government commodity subsidy and loan programs that would alter the attractiveness of converting erodible land in the future. Regardless, it seems likely that the "buster" and conservation compliance provisions will have important impacts on forest and range area (Moulton and Dicks 1987). The sodbuster provision is designed to discourage farmers from converting highly erodible lands, many of which are currently in pasture or range uses, to croplands. The swampbuster provision denies eligibility for farm program benefits to those who produce crops on converted wetlands. Such wetlands include bottomland hardwoods along the lower Mississippi River system, the pocosins of North Carolina, prairie potholes, and spruce permafrost in Alaska.

Over 80 million acres of existing cropland identified as highly erodible will be subject to conservation compliance. Many of such highly erodible acres will be placed under conservation practices through the CRP. As currently proposed, if farmers do not comply (i.e., implement a conservation plan or convert to a noncrop use) on highly erodible acres, they could lose government subsidies on all cropland acres. Procedures for full implementation and enforcement of provisions of the 1985 Farm Bill, such as conservation compliance, are being finalized and may be altered in the 1990 Farm Bill.

The uncertainty associated with the projections of land use in relation to the 1985 Farm Bill is heightened by the unknown contents of future national farm bills. Also some states, such as Minnesota, are adopting their own form of CRP programs.

The following pages discuss area projections by the geographic sections: the North and Great Plains, the South, the Rocky Mountains, and the Pacific Coast. Projections for three major forest ownership classes—public, forest industry, and farmer and miscellaneous private (table 23)—are discussed in more detail by Alig et al. (1989). Projections for range area change are less detailed (e.g., aggregated across ownerships) than those for forest area. The methods and assumptions used to generate the area projections are discussed in Appendix A.

PROJECTED FOREST AND RANGE AREA CHANGES

North and Great Plains

Total forest and range area in these sections is projected to increase (tables 21 and 22) because of increases in range area. The total forest land area in the North and Great Plains drops from about 170 million acres in 1987 to 165 million acres in 2040. Range area over the same period is projected to increase by 11 million acres or 15%.

The projections show slightly downward or fairly stable trends in many northern states. In some states such as Connecticut, Delaware, and Rhode Island, where substantial relative increases in population and economic activity are expected, the drop is fairly large. In most of the other states the projected changes are small relative to existing total forest area.

Timberland area is projected to increase in the mid-Atlantic states (New York, Pennsylvania, and West Virginia). This is linked to the changing nature of agriculture, particularly the decreases in farm area used in the dairy sector.

The distribution of forest and rangeland between private and public ownership has not changed appreciably in the last quarter of a century, and is projected to change little over the projection period. However, considerable transfers have occurred historically among the major classes of private forest owners—farmers, forest industry, and other private owners—that comprise over 80% of the forest land base.

The area in forest industry ownership is projected to be fairly stable. This is consistent with area projections for forest industry ownership in other parts of the U.S.

The projected area in the farmer and other private group drops about 5% by 2040. As in other sections, the projected decline in nonindustrial private forest area is largely due to the continued downward trend in land owned by individuals classified as farmers. Although the CRP will convert some highly erodible cropland into tree cover, thereby augmenting the shrinking area in farm forest, the extent of expected tree planting is small relative to the existing area of farm forest.

Rangeland in the two sections is almost all in the Great Plains states, as range area in the other northern states totals less than 0.5 million acres. Range area in the North and Great Plains is projected to increase by about 16 million acres by the year 2000, due primarily to the natural succession of grassland established under the CRP (Joyce 1989). The projected trend in range area is slowly downward after 2000, resulting in a 5% drop by 2040.

South

The land use situation in the South is relatively dynamic compared to other regions. Projected net area changes reflect the interlinked nature of the different sectors of the economy. For example, in addition to the direct conversion of forest land to urban and developed uses, other forest acres are converted to replace cropland lost to urban and developed uses (Healy 1985).

The net area of cropland is projected to drop by several million acres, while area in urban and related uses increases about 14 million acres by 2040. Pasture area is projected to drop by several million acres by 2040.

Table 23.—Area of timberland (million acres) in the United States, by ownership and section, 1952, 1962, 1970, 1977, and 1987, with projections to 2040

Ownership class and section	1952	1962	1970	1977	1987	Projections 2000	2010	2020	2030	2040
Ownership Class										
Public	153	152	150	144	136	134	134	134	133	133
Forest Industry	59	62	66	69	70	71	71	71	71	71
Farmer and other pvt.	296	304	288	278	276	270	267	263	260	257
Total, all classes	508	518	505	490	483	475	472	468	465	462
Section										
North and Great Plains	316	307	308	307	321	324	325	326	327	328
South	205	209	210	199	195	191	190	189	187	187
Rocky Mountain	63	63	61	57	58	56	56	56	56	56
Pacific Coast[1]	83	83	82	79	72	70	69	68	67	67
Total, all sections	508	518	505	490	483	475	472	468	465	462

[1] *Includes Alaska and Hawaii.*

Note: Data for 1952 and 1962 are as of December 31; all other years are as of January 1.

This is due in part to an assumed steady or slight increase in demand for livestock, caused by a leveling off or decline in per capita consumption of domestic red meat along with an excess supply of forage associated with the CRP. This situation is likely to put downward pressure on income from livestock.

A slow declining trend in forest land area is projected. Total forest land area in the South is projected to drop from about 203 million acres in 1987 to 193 million acres in 2040. The projected area changes are similar for timberland, which in this section comprises about 98% of forestland. The trends represented by the projections of forest area are fairly consistent across the South. The largest area reductions are projected for states such as Florida, where substantial relative increases in population and economic activity are expected, but the reductions are smaller than ones that occurred between 1952 and 1987. In some of the other states (e.g., South Carolina), the projected area increases slightly over the latter part of the period (Alig et al. 1989).

Two major sources of uncertainty regarding future land use in the South involve the future use of the forest land with potential for use as crop, and pasture land and cropland that are highly erodible or economically suitable for pine plantations. It is difficult to predict the impact of these forces on forest area—either up or down.

About 23 million acres of timberland in the South have high or medium potential for conversion to crop land (USDA Forest Service 1988). Although this land is concentrated to some extent in the states with coastal plains, there are substantial acreages in all states. If export demands for agricultural commodities increase more than currently expected or if crop yields increase at slower rates than assumed, all or a substantial part of this area could be cleared and used for crops.

A total of 22 million acres of marginal crop and pasture land in the South, including 8 million acres of highly erodible cropland, could yield higher rates of return to owners in pine plantations (USDA Forest Service 1988). Under the existing CRP of the 1985 Farm Bill over 4 million acres of highly erodible cropland could be planted to trees by 2000. The remaining marginal crop and pasture land, distributed in fairly large acreages through most southern states, would be another logical source of land for future conservation reserve programs or for programs to increase forest resource supplies.

Alternative futures were simulated to show the effects of converting all the forest land with high or medium potential for conversion to cropland, and the effects of planting to trees all of the crop and pasture land that would yield higher rates of return in pine plantations. Either of these alternatives would have major impacts on the forest resource supply situation in the South (USDA Forest Service 1988).

Currently, approximately 90% of the South's forest land is in private ownership. This percentage has changed little since the first surveys of the South's forest resources. The land use and management decisions of these owners have greatly impacted the southern forest resource supply situation. Area changes among the major groups of owners—forest industry and other private ownerships (which includes farmer, corporate, and other individual ownerships)—have been substantial. Around 16 million acres or 10% of the area in other private ownership has been converted to other uses or transferred to other owners, primarily forest industry, since 1952. Most of this area reduction has occurred on farmer ownerships.

Farmer ownership of forest land has declined because of several reasons. Many owners of forest land who were farm operators sold or passed on their holdings to new owners who did not secure their primary source of income from farming. In addition, many farmers increasingly secured their livelihood off farms and were subsequently classified as other individual private owners, i.e., all private owners except forest industry, farmer, and other corporate. Conversion to other uses, primarily agriculture, also has added to a reduction in farm forest area.

The timberland area in farmer ownership is projected to continue to decline by 17 million acres by 2040 (Alig et al. 1989). The projected reductions result in part from the continuing overall drop in the number of farms, caused by an economic shakedown in the farm economy. This trend is consistent across the South and in line with historical trends.

Other individual and corporate private owners have acquired many of the forest land acres that were once owned by farmers. Corporate owners include insurance companies, banks, and other institutional owners, but to be classified as such, they cannot own facilities that process timber.

Data that allow separate identification of corporate-based and other individual ownerships have been available only since 1977. Corporate private owners now hold 17 million acres of timberland in the South and have added approximately 3 million acres of this total since 1977. This acquisition was spread across all five forest management types—pine plantations, natural pine, mixed pine-hardwoods, upland hardwoods, and bottomland hardwoods—but the largest increases (over 30%) were in pine plantations and upland hardwoods (Alig et al. 1986).

Corporate ownership is projected to increase in size by approximately 7 million acres or by 40% of its current size (USDA Forest Service 1988). Part of the land is expected to be acquired through investment in southern pine timberland. As a result, pine plantation area in corporate ownership is projected to triple by 2040. It remains to be seen whether some corporate owners will divest of timberland after harvest of the current rotation's crop, or if they will invest in practices in line with long-run management of these timberlands.

Individual owners, the other component of the miscellaneous private ownership group, are the largest ownership class. This diverse set of owners hold over one-third of the southern timberland base, equal to 65 million acres. This is almost four times as much as corporate owners. Unlike the corporate class, individuals in the other private owner group are projected to reduce their holdings of timberland in the future. The projected reduction is approximately 4 million acres or 6% of the timberland area in this ownership by 2040.

Forest industry has steadily acquired timberland in the South since 1952. In 1987, industry owned 38 million acres of timberland in the South, approximately 20% more than in 1952. Most of industry's acquired acres have been in the South Central region, but the trend is upward across all the southern States.

In the past many forest products companies have found it advantageous to own large amounts of timberland. Some of the recognized advantages include an assured wood supply for mills that represent very large investments, augmentation of supplies of low-cost timber, a perceived hedge against inflation, and certain tax advantages. In addition, some banks have required certain levels of timberland to be owned as one condition for loans.

Although the latest Forestry Inventory and Analysis data do not show a significant reduction in the acquisition of timberland by industry, several factors now seem to be operating that reduce the attractiveness of industrial ownership of timberland. These include cash flow considerations, other investment opportunities in a company's portfolio, opportunities for land leasing and long term harvesting rights, and the increased substitution of more intensive forestry practices in place of land acquisition.

Given this current setting it has been assumed that the area in forest industry ownership will increase at a slower rate than in the past. Forest industries are projected to add one million acres over the next 45 years. This represents a 3% increase. Most of the acquired land is expected to be in the South Central region.

Public ownership of timberland in the South represents only about 10% of the total timberland base. Public ownership of timberland is projected to increase slightly, by 0.8 million acres or 4%, by 2040. Most of the increase is on other public ownerships (e.g., state lands), rather than national forests. Not included in the other public timberland expansion is some bottomland hardwood acreage that is likely to be acquired by state agencies and withdrawn from the timberland base to protect non-market resources.

Range area in the South is projected to increase by 14 million acres or 12% by 2040 (table 22). Approximately 97% of the rangeland in the South is in Texas and Oklahoma and competitive land use pressures between forest and range uses in the major timber growing portions of the South are relatively minor. The impacts of the CRP for range area are likely to be most important in Texas and Oklahoma. Over 10 million acres of highly erodible cropland in these states are projected to be converted to grassland by 2000. Some of this will likely revert to rangeland over the next two decades.

Land use pressures on range area from crop agriculture will also likely lessen over the projection period. The area of irrigated crop land is expected to decrease. Excess crop land in some cases will revert naturally to range cover.

Rocky Mountains

Total forest and range area in this section is projected to increase by about 7 million acres, or 1.5%, by the year 2040. The increase is due to projected expansion of range area, which occurs by the year 2000. The majority of range and forest acreage in this section is on public lands, but the projected increase in range area occurs on private lands.

Area of cropland is projected to drop by over 15 million acres, as highly erodible croplands are converted to tree and grass cover through the CRP. Area in urban and related uses is projected to increase slightly. Range area is projected to increase by several million acres. The primary reason is additions in range area from the natural succession of grass cover established under the CRP.

Projections show a slow declining trend in forest land area. The total forest land area in the Rocky Mountains drops from about 138 million acres in 1987 to 134 million acres in 2040. The projected net area changes largely reflect the direct conversion of forestland to urban and developed uses, and other acres converted for water development projects.

Overall, while future prospects are for total forest area to remain relatively stable, allocation of forest land for various uses may change (e.g., forest land may be withdrawn from timber production to protect other resource uses and values). It is likely that there will be further reductions in the area used to produce timber.

In proportion to the large number of range acres in this section—over 339 million acres—only relatively small changes in total range area are projected. The largest land use impact over the next decade will likely arise on private lands from the CRP. Over 10 million acres may be seeded to grass cover, and some of this may revert through ecological succession to range cover in subsequent years. The exact extent of such acreage will depend upon a number of factors, including possible legislative changes for the CRP, future CRP funding levels, changes in the agricultural outlook that might prompt subsequent conversion of some CRP acres back to agricultural uses after program requirements are met, and future conversion of some acres to nonagricultural uses.

Pacific Coast

The projections show somewhat opposite trends for forest and range area in the Pacific Coast section. Forest area is projected to drop by 8 million acres, or 4%, by the year 2040. Range area is projected to increase by 3 million acres, or 1%, over the same period.

The projected net area changes largely reflect the direct conversion of forest land to urban and developed uses. In particular, some forest area will be converted through urban expansion near Seattle-Tacoma, numerous localities in California, and in mixed forest-urban zones in Oregon. Other forest acres are likely to be converted to replace cropland lost to urban and developed uses.

The total area of cropland and pastureland is projected to remain essentially constant. Area in urban and related uses is projected to rise, and this will also increase the forested area that is intermingled with areas developed for nonforest use (Oswald 1984).

Area changes among the major groups of owners—forest industry and other private ownerships (which includes farmer, corporate, and other individual ownerships)—have been substantial. Around 5 million acres or 28% of the timberland area in farmer and other private ownership has been converted to other uses or transferred to other owners since 1952. Most of this area reduction has occurred on farmer ownerships.

Currently, industry owns approximately 23% of the Pacific Coast timberland, up from an 18% share in 1952. The area in forest industry ownership is projected to be fairly stable. Changes in how forestland is managed are likely to be more important than area changes for this ownership. As in other parts of the U.S., increasing amounts of timberland formerly owned by companies that operated mills are now owned by corporations who do not operate mills.

Projected reductions in farm forest area result in part from the continuing overall drop in the number of farms, caused by an economic slowdown in the farm economy. This trend is consistent across the U.S. and in line with historical trends.

Other individual and corporate private owners have acquired many of the timberland acres that were once owned by farmers. Corporate ownership is projected to increase in size. Part of the land is expected to be acquired through investment in timberland growing Douglas fir.

Area changes are projected to occur slowly here, compared to regions in the East. Much of the timberland is located on lands where forestry has a strong comparative advantage or is a residual use. Legislation in this region affecting land use practices is designed in part to promote stability of the private timberland base.

No major shifts among major land uses in Alaska are projected through 2040. Total area in forest and rangeland is projected to remain fairly constant, although further ownership changes are likely. Although total forest land area is projected to remain close to current levels, projected exchanges among ownerships include an additional 0.2 million acres of national forest land to be transferred to the state and 0.3 million acres to Alaska Native ownership, now classified as farmer and other private. Forest industry ownership is expected to remain negligible, although in time part of the land transferred to Alaskan Natives may be sold to forest industries.

The small projected increase in range area in the Pacific Coast Section occurs in California, Oregon, and Washington. Some range acres may be added through reversion of CRP grassland acres, due to natural succession, primarily in eastern Oregon and eastern Washington. The rate of conversion of brushlands to open grazing lands has decreased in California, due in large part to limitations on the use of prescribed fire.

PROJECTED AREA CHANGES FOR FOREST TYPES

North and Great Plains

Recent trends in area changes for forest types in these sections are projected to largely continue. The largest area change for forest types in the North and Great Plains is projected for northern hardwoods (figure 26), which increases by several million acres by 2040. This forest type is comprised of the climax and shade-tolerant maple-beech-birch, which is projected to increase because of successional forces. Sugar maple and yellow birch are important components of this type. The area in red maple is likewise expected to increase, particularly in the Northeast.

Conversely, oak-hickory area is projected to drop slowly. The forests of the North, being relatively diverse, are forests in transition. Reduction of wildfire is affecting area changes among types, and will continue to push the succession of oak forests to other species. Selective cutting has increased the dominance of sugar maple. Also adding to the projected drop in oak-hickory area is the conversion of such stands for the management of softwoods. However, the associated projected change is small because much of the land is held by nonindustrial private landowners who do not manage their forest stands intensively.

Area in aspen-birch area is also projected to drop slightly. The area in aspen-birch is sensitive to disturbances because it is a pioneer type. Therefore, the area of aspen-birch has been declining because most stands have not been intensively managed in the past. The rate of area loss is projected to slow because more stands are likely to be clearcut for panel production.

The area in softwood types is projected to be fairly stable over the projection period. Spruce-fir may decline slightly due to harvesting pressures, the increased use of clearcutting and environmental factors. The area in white-red-jack pine is also projected to drop slightly, and oak-pine is projected to gain in some cases at the expense of the white pine. The area in pitch-loblolly-shortleaf is expected to decline. Hemlock area is projected to increase due to natural succession in conjunction with lack of management on the extensive nonindustrial private lands.

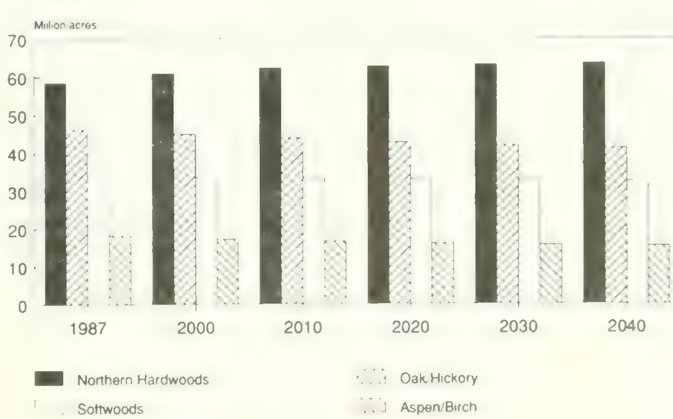


Figure 26.—Timberland area in the North, by forest type, 1987, with projections to 2040.

In both the North Central and Northeast regions, projected area changes for forest types are largely based on a continuation of recent trends (Spencer et al. 1988). Area for forest types in the Great Plains were projected in conjunction with those for the North Central region because of the similarity in forest types. The overall existing distribution among forest types is projected to change little over the projection period.

South

Projected changes in the area of the forest types in the South are consistent with recent historical trends (fig. 27). The largest area changes are projected for the pine types in the South, which represent some of the largest and most important area changes for forest types in the U.S. The area in pine plantations is projected to go up by approximately 22 million acres, thereby doubling by 2040. In contrast, natural pine area is projected to drop by 20 million acres or nearly half.

The net change in southern pine area is an increase of approximately three million acres by 2040. The projected doubling of planted pine area is largely due to the addition of pine plantations on forest industry lands. In addition, about 4 million acres of planted pine may be added through the CRP on nonindustrial private lands by the year 2000.

With management intensification on industrial lands, many harvested natural pine stands are being artificially regenerated. This conversion to planted pine allows genetically improved stock to be introduced on many acres and trees to be spaced in a manner which reduces the cost of subsequent industrial operations. The projected drop in natural pine area is also due to an assumed continuation of trends in substantial hardwood encroachment after harvest of pine stands on lands in other private ownerships (USDA Forest Service 1988). The other private ownerships contain the bulk of the natural pine area, and the projections assume that current trends in reforestation will largely continue.

Hardwood area in the South is projected to drop by about 10% by 2040. Several reasons for this projected decline include conversion of upland hardwood area to pine, especially on industrial lands: conversion of timberland on farms to cropland: and conversion of upland hardwood acreage to urban and developed uses.

Area in oak-pine or mixed pine-hardwood is projected to drop by over 6 million acres or about one-fifth of the existing area in this type. Much of this reduction occurs on forest industry lands, where many acres are converted to pine types. It should be noted that oak-pine is a relatively unstable type since it represents an intermediate stage in natural successional trends.

Rocky Mountains

Analysis of historical data indicated relatively slow exchanges among major groupings of forest types on a regional scale. Disturbances in forest stands are relatively infrequent in this section compared to other sections.

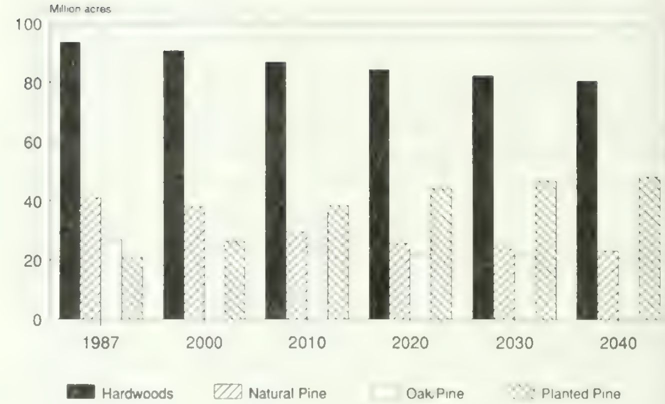


Figure 27.—Timberland area in the South, by forest type, 1987, with projections to 2040.

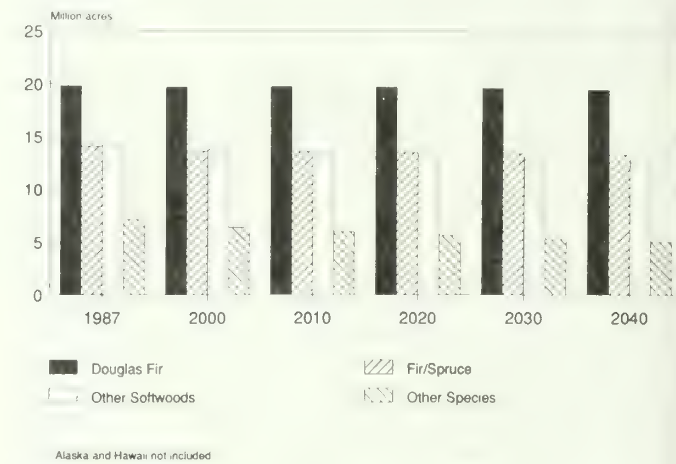


Figure 28.—Timberland area in the PNW Douglas fir region by forest type, 1987, with projections to 2040.

Forest land in the Rocky Mountain section was classified into hardwood and softwood types independent of the ownership class. Species-specific timber types were aggregated into hardwood and softwood types and used to compute the proportion of the forest land area in hardwood and softwood types. These proportions were projected to be the same in each decade between the years 2000 and 2040. In each decade, the timber type proportions were multiplied times the projected forest land area to obtain estimates of area by hardwood and softwood types.

Pacific Coast

Overall, projected net area changes for forest types in the Pacific Coast section are relatively small (figure 28). The most substantial changes are projected to occur on forest industry lands, as more acres are planted to Douglas-fir.

Hardwood area on the forest industry ownership is projected to decline. If recent stumpage price increases

for alder continue, the rate of alder conversion may lessen. Alder frequently becomes established after softwood harvests on other ownerships and its acreage has recently increased in some areas in western Oregon and Washington.

One management decision likely to continue is to allow more western hemlock to regenerate naturally, including mixtures of Douglas fir and western hemlock. Other trends discussed in the Pacific Coast section that are likely to continue in the foreseeable future include an increase in hardwoods in some coastal areas where conifers are harvested. In the interior, tolerant species such as white fir and incense cedar may increase as pines are removed from mixed conifer stands.

The projected drop in the area of "other softwoods" primarily involves ponderosa and lodgepole pine. Many of these acres are in eastern Oregon and Washington. The projections are based on a continuation of recent trends.

Projected timberland losses on farmer and miscellaneous private lands are distributed across all forest types. This is also the case for other public lands.

PROJECTED CHANGES BY SITE CLASS AND OTHER PRODUCTIVITY IMPACTS

Site, a measure of the inherent capacity of land to grow trees, is one of the important determinants of changes in the forest resource. However, analysis of data first assembled around the mid-1960s for the South (one of the major timber growing regions and probably the most dynamic in terms of land base changes), indicates there have been no major net changes in the regional distribution of timberland by site class. For example, the last two surveys in the Southeast indicate that overall there have been only relatively minor shifts in the proportions of area by site class, toward the higher classes.

Based on the analysis of historical site data for the South and the general lack of data indicating otherwise for other sections, it was assumed in this study that the distribution of timberland among the site classes would not change significantly over the projection period. It should be noted that trends may vary in localized areas. Investments in intensive management can alter the inherent productivity in many cases. In the South the conversion of many forest acres to pine plantations implies a shift toward a higher site class. An example is the upgrading of substantial acreages of low productivity land in the coastal plain that are being drained, site prepared, bedded, and planted to pine.

Projected changes in rangeland condition classes (see Chapter 1) and related questions are discussed along with an analysis of the forage resource in a supporting RPA document (Joyce 1989). No major changes are projected.

Another consideration when examining the future productivity of forest and rangelands is the continued spread of "irreversible" developed or built-up uses over the rural landscape. In recent decades, this has led many observers to wonder about the degree to which their expansion was affecting the availability of land for agricultural and forestry commodity production and for recreation. Hence, the growing attention paid to the "urban-rural interface" and associated forest and rangeland management questions. Bureau of the Census statistics for the first half of the 1980s indicate a reversal of the relative rural growth pattern of the 1970s. However, physical occupation of the land base by built-up uses is projected to remain well below 10% over the next several decades for the U.S. (Alig and Healy 1987).

Expansion of built-up uses into rural areas has other important impacts besides the actual conversion of forest and rangeland. Expectations of neighboring landowners about the future use of their land may be influenced, generally reflected in higher asking prices for land. Property taxes may also rise, reflecting the new, higher land values. Composition of landownership may change, with an increasing proportion of landowners being primarily nonfarmers, although the land may still be used for farming, often on a rental basis. In addition, as expectations about future urban uses rise, land is typically divided into smaller parcels. This can have profound impacts on the economics of forestry, even when the land is not physically altered in any major way (Healy and Short 1981). Little information exists regarding the amount of higher quality forest and rangeland that may be converted to built-up uses. There are also "juxtaposition effects"—spatially bounded externalities that affect adjoining or nearby land (Healy 1985). These effects may be either positive (e.g., a new reservoir raises recreational attractiveness of nearby forest land) or negative (e.g., new residents object to spraying of herbicides or to clearcuts or controlled burns on forest land) (Bradley 1984).

Existing urbanization measures also provide little information on the extent to which many nonresidential lands, for which site improvements occupy only a small portion of relatively large tracts, are classified as built-up. For example, rural industrial plants and associated improvements (e.g., parking lots) often occupy 10% or less of their sites, with the remainder often in forest or range cover. Open portions of developed sites are seldom used for commodity production but may be available for such use should future demand warrant it.

Another consideration in the long-term outlook for changes in forest area is the implications of changing climate. Possible climate change is a less than certain issue, but it has important implications in terms of impacts on forest growth (Rose et al. 1987) and possible changes in total forest area, as well as the relative distribution of forest types. There is much ongoing related research and monitoring of the possible effects, and this should assist in assessing its importance along with the other factors that influence forest area changes.

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APPENDIX A
AREA PROJECTION METHODS

Methods For Projecting Area Changes by Major Land Uses

Methods for projecting area changes for major land uses and associated waters in past Assessments primarily involved expert opinion approaches. Projections of area changes by land use for most regions in the 1989 Assessment were derived from a blend of (1) econometric analysis of historical relationships among major land uses and key variables (e.g., Alig 1986) and (2) expert opinions. This blend is necessary because land use changes involve a complex interaction of factors, and in some cases research is still underway in attempting to quantify the relationships among such factors. This approach involves the application of total land base constraints so that areas in all uses must sum to the total land area. Specific methods used for each region are described in more detail by Alig et al. (1989).

Improved resource and ownership data have allowed estimation of econometric models of land allocation that allow simultaneous, dynamic consideration of competing uses. Quantitative models are available for some regions to investigate the forces that underlie changes in forest and range area and to use them for projections.

Modeling area changes for land uses and ownerships in each region proceeded in two stages. In the first stage, net area changes for all major land uses/forest ownerships were projected simultaneously to assure that fixed land base constraints were met. Projections of public forest and range area were external to the model and were based on the expert opinions of agency personnel and other experts knowledgeable about the management and acquisition of public land in each region.

In the second stage of the area modeling, which only involves timberland, area changes were projected for forest management types by forest ownership. Area changes for forest management types reflect influences of both natural successional forces and land management activities or disturbances (Alig and Wyant 1985). Projections of area changes by management types are important because they reflect differences in management practices among ownerships and among states. They directly reflect tree planting, one of the chief indicators of management intensity.

Factors influencing private land use conversion, forest type transition, and the sources and quality of data vary greatly among regions. Because of this, models were developed individually for each region, and are described separately for each region by Alig et al. (1989).

Projections of area changes for major private land uses are based on the theory that private land tends to be used for the purpose that produces the economic maximum (including financial and nonfinancial benefits) for the owner. Thus the best use of land is largely determined by the expected difference discounted back to the present between the value of the output and the cost of production for alternative uses. Because costs, prices, and techniques of production change over time, so does the optimal use of land. A good historical example of this is the abandonment of the wheat farms in northern Wisconsin after the increase in production in the Great Plains and the corresponding decline in the price of wheat.

Results from research studies for the North (Plantinga et al. 1988, Howard and Lutz 1989), South (Alig 1985), and Pacific Coast (Parks 1986, 1988a; Berck and Parks 1987) sections, along with some input based on expert opinions, were used to develop regional area projection models. Series of econometric equations were developed to project area in crops, pasture/range, urban/ other, industrial forest, and farm and miscellaneous private forest uses. Expert opinion approaches were used for the Rocky Mountains and Alaska. Input data for the dependent variables were collected from the USDA Forest Service Forest Inventory and Analysis (FIA) units. The initial 1987 acreage data for all land classes were obtained from the RPA data base (Waddell and Oswald 1986).

Equations from regional research studies (e.g., Howard and Lutz 1989), which had land uses or forest ownership areas as the dependent variables, were incorporated into a projection system similar to that described by Alig (1985). If a research-based equation for a particular nonforest use was not available, projections of area changes for those uses—crops, pasture/range, or urban and other lands—were constructed from existing studies (e.g., urban area projections by the USDA Economic Research Service (1987) and Alig and Healy (1987)) or expert opinion, augmented by analysis of data series (e.g., Frey and Hexem 1985) on land use changes.

Projections of changes in forest area for the South are consistent wit those for the recent comprehensive study of the forest resource supply situation in the South (USDA Forest Service 1988). It should be noted that Kentucky has been added here to the 12 states examined in the Southern Study and the area projections include lands under long-term lease by forest industry was part of the nonindustrial ownership class (such acres were included under the industry class in the Southern Study).

Projections of area change for rangeland were a blend of exogenous projections from the National Interregional Agricultural Production (NIRAP) model, adjusted for likely land use impacts of the CRP (Joyce 1989). NIRAP's projections of land use change are based primarily on extrapolation of historical trends. About 40 million acres

of highly erodible cropland are expected to be placed in grass cover under the CRP nationwide, and some of this acreage may revert naturally to rangeland or forest over time. Most of the natural reversion to rangeland occurs between 1990 and 2000. The range area projections were included as part of the basic assumptions developed by the USDA Forest Service and SCS (USDA Forest Service 1987). A related assumption is that some type of conservation reserve program will remain in effect throughout the projection period.

The only exception to this projection process is that urban areas and public areas are accepted as given and were not subjected to any necessary adjustments to meet total land base constraints. A hierarchical approach dictated that urban and developed uses were dominant in the land allocation according to the conversion pressures, related to the much higher land prices that urban and developed uses command compared to agricultural and forestry uses. Such developed uses are essentially irreversible in the foreseeable future and the trend in their area is upward. Changes in public forest and range area are relatively stable in general compared to private timberland, and were incorporated as a fixed vector.

Area projections for public ownerships (e.g., state, BLM) were made by agency personnel in regional offices. For example, area projections for national forest land of the USDA Forest Service for all regions reflect the forest planning process (Alig et al. 1989). Projections include any timberland withdrawals for likely wilderness areas, roads, powerlines, reservoirs, and associated uses.

A variety of assumptions were used to project the diverse set of variables that influence private land use changes in the projection system. Because highly accurate predictions of these independent variables for several decades into the future are not possible, reasonable assumptions were made based on historical trends, developments that affect those trends, and the expectations regarding future changes. Assumptions used in making projections for population, personal income, and inflation rates are those used for the 1989 RPA Assessment and 1986 RCA Appraisal (USDA Forest Service 1987).

Many of the forces that have caused the recent changes in area of forest and rangeland will surely continue to influence changes in the future. Thus, in making projections of area changes, it has been assumed that determinants such as population, income, agricultural productivity, agriculture exports, and prices of agricultural crops and timber products would continue to influence land use changes (Alig 1985).

Assumptions pertaining to the future rate of change in agricultural productivity and associated land incomes were derived from the 1986 RCA Appraisal (USDA Soil Conservation Service 1987). RCA assumptions on the annual rate of increase in yield vary by crop, but the rate of increase up to the year 2000 is higher in all cases than the increase projected from 2001 to 2030. For example, productivity for field crops was assumed to increase by 1.9 percent annually up to the year 2000 and then slow down to 1.2 percent annually. Real product prices for agricultural products were assumed to remain essentially constant over the projection period. Slow increases in the export of agricultural products are projected. Livestock incomes were projected assuming constant real prices and no changes for productivity growth.

Stumpage price projections used in the land use modeling are those generated by the Timber Assessment Market Model (TAMM) for the 1989 RPA Assessment. Interaction with TAMM allows projected changes in timberland area to respond to economic forecasts.

The models project area changes for timberland by owner group (industry, farmer, and miscellaneous private), pasture/rangeland, and urban/other land. Changes in the area of timberland—land capable of growing at least 20 cubic feet of industrial wood per acre per year and not reserved for other uses—are major determinants of changes in net annual growth, inventory, and other components of the forest resource. A large percentage of private forest land is classified as timberland, and future total area trends for these two land base descriptions are likely to be similar.

Changes in land area are input to projection models (e.g., timber inventory projection) for different forest and rangeland resources each decade. For example, natural afforestation or active regeneration are additions to young age classes in timber inventory modeling (Parks and Alig 1988). Land clearing or harvest without subsequent regeneration may remove acres from the inventory.

At least three groups of input data are required for the area change projection models: (1) cross-section or time series data to estimate model parameters; (2) current land use data or descriptions of the forest land base from FIA remeasurements, and (3) projections of predetermined variables. The first two groups are necessary to estimate the models; the third is necessary to simulate future area changes for land uses.

Preliminary projections of forest and range area derived from the econometric system and the assumptions described above were modified in response to reviews by the state forestry agencies, industry representatives, public land management agencies, and other experts in each region. The system and the projections were also reviewed by technical experts from the Forest Service, forest industries, and forestry schools.

Methods For Projecting Area Changes by Forest Type

Changes in area among forest types affect both the nature and volume of timber available from forests. For example, decreases in timber production can occur when commercial species are crowded out by noncommercial species. Failure to account for these forest type changes can lead to unjustified optimism about future timber production. In addition, forest type changes are important when assessing prospective supplies of other forest resources.

Forest type transitions are simulated by multiplying an initial vector of acres by forest type by a transition probability matrix. The matrix of transition probabilities

is generated by multiplying a vector of disturbance probabilities by a matrix of conditional probabilities for transitions among forest types, each with the general form:

$$P(D_{k(i,j,t)})\ P(FT_{i,j',t+1} \mid D_{k(i,j,t)}, FT_{i,j,t}).$$

This represents the probability (P) of a disturbance (D) of type k on ownership i and forest type (FT) j in decade t multiplied by the conditional probability that a unit area of timberland on ownership i at decade t + 1 will be in forest type j′, given the disturbance (Alig and Wyant 1985). These probabilities are derived from sample relative frequencies of remeasured Forest Service inventory data, classified into three disturbance categories (no management, regeneration harvest, and miscellaneous) and three ownership groups (farmer, miscellaneous private, and industry).

If no data on disturbances are available and plots have been remeasured at least once, the simpler probabilities

$$P(FT_{i,j',t+1} \mid FT_{i,j,t})$$

which are an average over all disturbance regimes (including no disturbance) and owner groups, could still be estimated from sample relative frequencies. This projection framework was applied, in conjunction with adjustments suggested by the respective FIA units, for the North Central region (Parks 1988b) and Pacific Northwest Westside (Parks 1988c).

Glossary of Land Area Terms used in the Analysis

Bureau of Land Management (BLM)—An ownership class of federal lands administered by the Bureau of Land Management, U.S. Department of the Interior.

Commercial species—Tree species suitable for industrial wood products.

Douglas-fir subregion—The area in the states of Oregon and Washington that is west of the crest of the Cascade Range.

Ecological status—The degree of similarity between the present community of a site. Considers only secondary succession.

Farmer—An ownership class of private lands owned by a person who operates a farm, either doing the work himself or directly supervising the work.

Federal—An ownership class of public lands owned by the U.S. Government.

Forest industry—An ownership class of private lands owned by companies or individuals operating wood-using plants.

Forest land—Land at least 10% stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10% stocked with forest trees, and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West, and afforested areas. The minimum area for classification of forest land is one acre. Roadside, streamside, and shelterbelt strips of timber must have a minimum crown width of 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet in width.

Forest trees—Woody plants having the potential for one erect perennial stem or trunk at least 3 inches in diameter at breast height (dbh) or 4-1/2 feet, a more or less definitely formed crown of foliage, and a height of at least 16 feet.

Forest type—A classification of forest land based upon the species presently forming a plurality of the live-tree stocking. Synonymous to forest ecosystem.

Growing stock—A classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor. Cull trees are excluded. When associated with volume, includes only trees 5.0-inches dbh and larger.

Hardwood—A dicotyledonous tree, usually broad-leaved and deciduous.

Land area—(a) Bureau of Census: The area of dry land and land temporarily or partly covered by water, such as marshes, swamps, and river food plains; streams, sloughs, estuaries, and canals less than 1/8 statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area. (b) Forest Inventory and Analysis: same as (a) except that the minimum width of streams, etc., is 120 feet, and the minimum size of lakes, etc., is 1 acre. This latter definition is the one used in this publication.

National Forest (NF)—An ownership class of Federal lands, designated by Executive Order or statute as National Forests or purchase units, and other lands under the administration of the Forest Service including experimental areas and Bankhead-Jones Title III lands.

Nonforest land—Land that has never supported forests and lands formerly forested where timber management is precluded by development for other uses. (Note: Includes area used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide, and clearings, etc., more than 1 acre in size, to qualify as nonforest land.)

Nonstocked areas—Timberland less than 10% stocked with growing-stock trees.

Other federal—An ownership of federal lands other than those administered by the Forest Service or the Bureau of Land Management.

Other forest land—Forest land other than timberland and reserved timberland. It includes unproductive forest land, which is incapable of producing annually 20 cubic feet per acre of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness. It also includes urban forest land, which due to its location is unavailable for sustained timber harvesting.

Other land—Nonforest land less the area in streams, sloughs, estuaries, and canals between 120 and 660 feet wide and lakes, reservoirs, and ponds between 1 and 40 acres in area (i.e., nonforest land less non-Census water area).

Other private—An ownership class of private lands that are not owned by forest industry or farmers.

Other public—An ownership class that includes all public lands except National Forest.

Ownership—The property owned by one ownership unit, including all parcels of land in the United States.

Ownership unit—A classification of ownership encompassing all types of legal entities having an ownership interest in land, regardless of the number of people involved. A unit may be an individual; a combination of persons; a legal entity such as a corporation, partnership, club, or trust; or a public agency. An ownership unit has control of a parcel or group of parcels of land.

Ponderosa pine subregion—The area in the states of Oregon and Washington that is east of the crest of the Cascade Range.

Productivity class—A classification of forest land in terms of potential annual cubic-foot volume growth per acre at culmination of mean annual increment in fully stocked natural stands.

Rangeland—is a type of land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs. Rangelands include natural grasslands, shrublands, savannas, most deserts, tundra, alpine plant communities, coastal marshes, and wet meadows. Plant communities dominated by introduced species that are managed like rangeland are also included in this type of land. Rangeland also includes many riparian vegetation types.

Reserved timberland—Forest land that would otherwise be classified as timberland except that it is withdrawn from timber utilization by statute or administrative regulation.

Softwood—A coniferous tree, usually evergreen, having needles or scalelike leaves.

State—An ownership classification of public lands owned by states or lands leased by states for more than 50 years.

Timberland—Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note; Areas qualifying as timberland have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)

Forest Service Regions and Assessment Regions

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-182**

Improving Southwestern Riparian Areas Through Watershed Management

Leonard F. DeBano and Larry J. Schmidt

PREFACE

Riparian areas in the Southwest contain important plant ecosystems in two widely different environments—along small, higher elevation first- and second-order streams, and along large rivers, some of which pass through hot desert environments. These arid environments make the sustenance of the riparian plant communities in these areas extremely tenuous. This paper describes opportunities for better managing existing southwestern riparian areas, and creating hydrologic regimes more favorable for rehabilitating existing or creating new riparian ecosystems. Also, it contains information on the consumptive use of water necessary for supporting riparian ecosystems in these environments. It is intended to serve as a state-of-the-art report on riparian hydrology, and provide general guidelines for improving hydrologic relationships in naturally occurring and man-enhanced riparian areas throughout the Southwest.

Small upland streams support riparian areas that are intimately interrelated with the surrounding watershed. As a result, they reflect both the biotic and abiotic conditions of the watershed in which they exist. The relationship between watershed and riparian areas depends on a balance between "watershed condition" and "riparian health." This concept is used as the basis for discussing management and rehabilitation of these areas. Management opportunities for rehabilitating these upland riparian areas generally involve improving watershed condition, modifying plant cover, installing small channel structures or gully plugs, or using a combination of all these rehabilitation techniques. Implementing these practices can alter both the amount and duration of streamflow. A promising technique for increasing both amount and duration of streamflow through riparian areas in Arizona chaparral involves upslope vegetation manipulations where deep-rooted shrubs are replaced with shallower rooted grasses requiring less water. Riparian enhancement in response to cover manipulation is not as promising in pinyon-juniper, ponderosa pine, and mixed conifer forests. Before implementing different watershed treatments, land managers need to be continually aware of the strong relationship between watershed condition and riparian health so they are better able to assess any negative and positive treatment effects. In nearly all cases this requires an interdisciplinary approach to management, covering abiotic as well as biotic factors operating within a watershed.

Extensive riparian areas in the Southwest can develop along larger rivers in response to large dams constructed for flood control or water storage because they stabilize erodible channels and extend streamflow duration. Sediment deposited in the reservoirs above these large structures store and release water slowly over time, sometimes producing perennial streamflow. Deposited sediments also provide a nutrient-rich substrate favoring plant establishment and growth. Case studies are presented where large and intermediate channel structures have enhanced riparian establishment.

Although instream structures can create a more favorable environment for riparian ecosystems, they may also change the channel dynamics of both up- and downstream channel reaches. Also, the vegetation invading these sites is usually dominated by saltcedar, which is of lower value for wildlife habitat than native riparian plant species that formerly occupied these sites. This mix of advantages and disadvantages must be considered in any management decision or plan.

Several naturally occurring processes, operating at different scales, also provide the moving forces for floodplain and associated riparian area development. These include changes in channel slope resulting from landslides, tributary alluvial fans, log step formation, beaver dam construction, and geologic processes such as cienega formation. Effective management of these naturally occurring riparian areas requires understanding the hydrologic and hydraulic processes responsible for their formation.

USDA Forest Service
General Technical Report RM-182

December 1989

Improving Southwestern Riparian Areas Through Watershed Management

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Abstract

This paper reviews opportunities and watershed restoration techniques available for rehabilitating and enhancing riparian ecosystems in southwest environments. As such, it is intended to serve as a state-of-the-art report on riparian hydrology and improvement in both naturally occurring and man-made riparian areas throughout the Southwest.

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CONTENTS

Improving Southwestern Riparian Areas Through Watershed Management

Leonard F. DeBano and Larry J. Schmidt

INTRODUCTION

Riparian areas are ecologically important habitats throughout the Southwest. They are sensitive to disturbance and degradation, but at the same time are resilient and can recover rapidly when managed properly. Although much has been written on vegetation structure and classification (Johnson and Lowe 1985, Swanson et al. 1988, Szaro 1989), water consumption (Horton 1973), grazing effects (Platts and Raleigh 1984, Skovlin 1984), and wildlife (Johnson et al. 1985, Thomas et al. 1979) in riparian areas, only recently have publications documented how different watershed practices have rehabilitated existing, or enhanced potential, riparian areas throughout the Southwest (DeBano and Hanson 1989, DeBano and Heede 1987, DeBano et al. 1984, Heede and DeBano 1984, Szaro and DeBano 1985).

Riparian areas can be improved by either riparian enhancement or rehabilitation. Riparian enhancement is used in the context defined by Platts and Rinne (1985): "returning the riparian/stream habitat to a more productive condition by natural or artificial means." Enhancement includes those activities that change streamflow regimes so as to encourage the establishment of new riparian areas. Riparian rehabilitation, on the other hand, is linked to describing those situations where deteriorated riparian areas are improved, but may not necessarily be restored to pristine conditions. Likewise, watershed rehabilitation is used rather than watershed restoration because the former implies only that a watershed is being improved, not necessarily restored to a pristine or former condition.

When discussing the effect of watershed practices on riparian improvement, it is useful to distinguish between small riparian stringers along small streams passing through higher elevation rangelands, brush fields, and forest types as contrasted to the extensive riparian ecosystems along large rivers passing through lower elevation desert environments.

Our current understanding of riparian area hydrology in the Southwest is based mainly on past water augmentation research conducted mainly in the 1950's and 1960's in both the upland and lower elevation environments (Hibbert et al. 1974, Horton 1973). In both environments, a major emphasis of past research on water augmentation emphasized phreatophyte control (Horton 1973). Because of this past emphasis, current watershed managers are often incorrectly viewed as being mainly interested in eradicating phreatophyte vegetation in riparian areas to increase water production. Modern watershed managers recognize riparian areas contain important plant ecosystems that interrelate the contributing watershed with the aquatic ecosystem.

Healthy riparian areas stabilize stream channels, provide storage for sediment, serve as nutrient sinks for surrounding watersheds, and improve the quality of water leaving the watershed. They also provide water temperature control through shading, reduce flood peaks, and serve as key recharge points for renewing ground water supplies (Groeneveld and Griepentrog 1985, McGlothlin et al. 1988, Zauderer 1987). Although many past watershed management action programs have been implemented primarily for watershed improvement of upland areas and for water storage and flood control in downstream environments, they provided an added benefit of rehabilitating or enhancing riparian areas under a wide range of climatic conditions.

The overall objectives of this document are to provide (1) a state-of-the-art report on riparian hydrology in the Southwest, and (2) general guidelines for improving hydrologic relationships in naturally occurring and man-induced riparian areas throughout the arid Southwest. As a result, the document focuses on improving riparian areas in harsh arid environments where intermittent and ephemeral streamflow predominate. This document is not intended to be a review of the direct effect of grazing on riparian areas, nor will it deal with the management of riparian areas for fishery habitat. Excellent state-of-the art papers are available elsewhere on the impacts of grazing on riparian habitat (Skovlin 1984) and management for stream habitat (Platts and Raleigh 1984, Platts and Rinne 1985, Platts et al. 1987, Rinne 1988). Therefore, the more specific objectives of this paper include: (1) reviewing riparian terminology, (2) presenting a conceptual relationship between watershed condition and riparian health in arid upland areas, (3) presenting guidelines for improving watershed condition and riparian health, (4) discussing the role of instream structures in riparian rehabilitation, (5) using several case studies to illustrate a wide range of watershed practices that have enhanced establishment of riparian ecosystems, (6) analyzing the effect of different watershed practices on stream and channel dynamics in riparian areas, (7) reviewing past research and estimates of water use by southwestern riparian ecosystems, and (8) discussing further hydrologic research needed in riparian areas.

RIPARIAN TERMINOLOGY

Numerous terms have been coined in riparian literature. This wide array of terminology has often led to confusing, and in some cases conflicting, use of similar terms for the same entity being described. Definitions and terminology have been reviewed by several authors (Anderson 1987, Johnson and Carothers 1982, Johnson

and Lowe 1985, Johnson et al. 1984, Lowe et al. 1986, Platts et al. 1987, Swanson et al. 1982) and are summarized in appendix A.

Because of the wide disparity in commonly used riparian terms, the specific definitions used by the U.S. Forest Service will be used whenever possible throughout this document. The U.S. Forest Service is currently using the following definitions in its manual (USDA Forest Service 1986).

Riparian areas.—Geographically delineable areas with distinctive resource values and characteristics that are comprised of the aquatic and riparian ecosystems.

Riparian ecosystem.—A transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; identified by soil characteristics or distinctive vegetation communities that require free or unbound water.

Aquatic ecosystems.—The stream channel, lake or estuary bed, water, biotic communities, and the habitat features that occur therein.

It is important to note, according to these definitions, that the term "riparian area" encompasses both the aquatic and riparian ecosystem. This definition is also used without being restricted to conditions where hydric soils or perennial surface flow are present. Hydric soils may not be evident in some areas because of extensive destruction in former riparian areas. Likewise, the appearance of dry channels does not necessarily indicate that a perennial water supply is not within the rooting zone of riparian plants. Additional terms will be defined as used throughout the document.

CONCEPT OF RIPARIAN HEALTH AND WATERSHED CONDITION

The objective of this section is to develop a conceptual model relating *riparian health* and *watershed condition* for upland watersheds. The upland watersheds are those drained by first- and second-order streams. Although many of the relationships required for such a model are available in the literature, they have not previously been synthesized into a body of information that can serve as guidelines for resource managers.

Concepts and Definitions

The term *watershed condition* describes the state of a watershed. It effectively integrates such resource factors as vegetation cover, flow regime, sediment and nutrient output, site productivity (Hanes et al. 1986, Solomon et al. 1982), and the associated riparian areas. Although dense and sparse cover are sometimes used synonymously with good and poor watershed condition, other attributes are included in this distinction (table 1). The condition of watersheds is important because it also influences the quality, abundance, and stability of downstream resources and habitat by controlling production of sediment and nutrients, influencing streamflow, and modifying the distribution of chemicals throughout the environment.

Riparian health, as an important component of watershed condition, refers to the stage of vegetative, geomorphic, and hydrologic development, along with the degree of structural integrity exhibited by a riparian area. This concept also encompasses the complex relationships existing between riparian areas and the surrounding watersheds (DeBano and Schmidt 1989). Considered over long time spans, riparian areas reflect both biotic and abiotic conditions of the watershed in which they reside, although they may not necessarily be synchronized at any given point in time.

Relationships Between Watershed Condition and Riparian Health

A healthy riparian area is in dynamic equilibrium with the stream. In this condition, the riparian vegetation remains vigorous and does not encroach into the channel, nor does streamflow expand meander belts through the riparian area, or impact it by aggradation or degradation of the channel bed. The equilibrium between channel aggradation and degradation in riparian areas can be illustrated by a conceptual model (Lane 1955) for describing relationships between sediment production and magnitude of streamflow, which was later expanded by Heede (1980) for stream dynamics. This model depicts

Table 1.—Attributes of good and poor watershed condition.

	Good level		Poor level
A	Vegetation and litter cover capable of absorbing precipitation energy, increasing infiltration, and extending release of flow to channels.	A′	Storm energies detach soil, seal soil pores, increase erosion, thereby creating a flashy sediment-laden runoff, resulting in ephemeral flows.
B	Minimal drainage density channel network is necessary for conveying runoff from watershed.	B′	Expanding drainage density and channels to accommodate increased surface flow.
C	Large temporary storage of water in the watershed system.	C′	Rapid conveyance of water from watershed with minimal retention of water for later release.

a healthy riparian area as one maintaining a dynamic equilibrium between streamflow forces acting to produce change and vegetative, geomorphic, and structural resistance (fig. 1).

The attributes of healthy and unhealthy riparian areas are given in table 2. When this natural system is in dynamic equilibrium, it maintains a level of stability that permits internal adjustments of variables without producing rapid changes in the system. This resilience, or resistance to rapid change, results from a combination of factors acting together in the riparian area and throughout the watershed in general. Most important of these is vegetation. Flows in excess of channel capacity overflow onto floodplains where vegetation and other debris provide a substantial resistance to flow and act as filters, or traps, for sediment. During these bank overflows, opportunities are available for germination and establishment of certain riparian plant species (Asplund and Gooch 1988, Brady et al. 1985, Szaro 1989).

The balance between watershed health and riparian condition can be defined in terms of four possible combinations of watershed condition and riparian health (fig. 2). The likelihood of the four combinations vary in time and space. In general, however, it is likely that healthy and productive riparian areas reflect a balance between the riparian ecosystem, including the associated channels, and the hydrologic and geomorphic processes operating in tributaries of a watershed that is in good condition. At the other end of the spectrum, it is also very likely that unhealthy riparian areas reflect poor watershed conditions. It is possible, although less likely, to have other combinations of watershed condition and riparian health because of lag periods between changes on the watershed slopes and in the riparian areas. For example, it is possible to have an unhealthy riparian area while the surrounding watershed is in good condition because of concentrated overgrazing in the riparian area. Over long enough periods of time, misuse of riparian areas may lead to channel incision and gully development throughout the surrounding watershed. It is least likely to have a healthy riparian area present when the surrounding watershed is in poor condition, although installation of structures and exclusion from grazing may temporarily improve riparian areas on watersheds that are generally in poor condition.

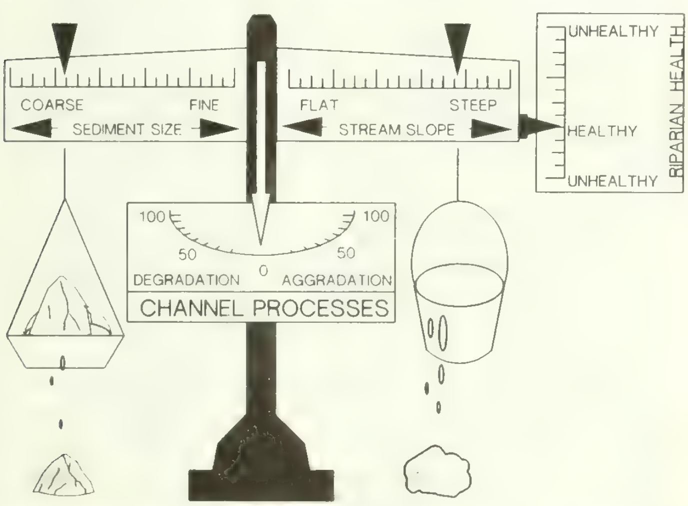

Figure 1.—Healthy riparian areas depend upon a dynamic equilibrium between channel aggradation and degradation processes. The equilibrium illustrated oscillates both in time and space throughout the channel network. The channel network adjusts in form and slope to handle increased storm flows with limited perturbation of channel and associated riparian plant community.

A healthy watershed/riparian system is also resilient. Most of the potential runoff produced by storms immediately infiltrates into the soil (Horton 1937) and thus provides more regulated flow, which is characteristic of runoff generated by a variable source area model (Hewlett and Troendle 1975), except where water is delivered rapidly to the channel by pipeflow. Excess runoff reaching the channel increases flow volume and velocity, and this short-term increase in flow causes an oscillation in the equilibrium between erosion and deposition in the riparian area. While the balance tips back and forth, it is quickly dampened by the channel characteristics and results in no major change in the central tendency toward maintaining a dynamic equilibrium. When the resilience, or elasticity, of the system is not violated, a new dynamic equilibrium condition can be established.

The interrelationship between watershed condition and riparian health is well substantiated by historical documentation. Historical accounts of many riparian areas in the Southwest (Dobyns 1981, Minckley and Rinne 1985) portray them as stable, aggrading stream networks containing substantial amounts of organic debris and supporting large beaver populations. Under these conditions, forested headwater tributaries provided a continuous supply of small and large organic debris that formed log steps in smaller streams (Heede 1972, 1985a, 1985b) and large accumulations of logs and other organic debris along higher order, low-elevation mainstreams (Minckley and Rinne 1985). Naturally occurring floodplain and channel structures, along with living plants, dissipated energy, controlled sediment movement and deposition, and thereby tended to regulate and sustain flow that provided a hydrologic environment sufficiently stable for maintaining and perpetuating healthy riparian ecosystems. The energy dissipation decreased flow velocities in stream channels and on floodplains, which improved percolation of water into subsurface storage. This delaying effect was likely enhanced because many stream channels were above fault-fracture zones that lead to underground aquifers (McGlothlin et al. 1988).

Water stored in these high-elevation aquifers was available and, when slowly released, supported late-season flows in downstream riparian areas. Sufficiently dense vegetation and ground cover were also present throughout the watershed, which allowed precipitation from storm events to infiltrate into the soil. Water passing slowly through the soil mantle sustained a dependable perennial streamflow necessary for maintaining downslope riparian ecosystems.

It is also important to note that under this pristine regime, most storm events infiltrated into the soil; as a result, channel networks were less extensive (Carlston

Table 2.—Important attributes of healthy and unhealthy riparian areas.

	Healthy		Unhealthy
A	Efficient channel shape with narrow channel that conveys all flows less than that of the mean annual flood (2.33-year recurrence interval) with minimal bank and channel erosion.	A′	Inefficient channel shape often braided or shallow and widely fluctuating. Most flows confined in channel. Severe bank and channel erosion and expanding width.
B	Stream power < critical power.	B′	Stream power > critical power.
C	Channels have low hydraulic energy gradient and high sinuosity.	C′	Channels have high hydraulic energy gradient and low sinuosity.
D	Flows above mean annual flood leading to low energy flow on the floodplain: dissipating energy, filtering sediment, and capturing sediment.	D′	Flows above mean annual flood lead to high velocity on the floodplain. Limited energy dissipation. Removal of sediment and nutrients from floodplain.
E	Log step and transverse gravel bar formation in confined channels. Infrequent occurrence of knickpoints. Well-developed meanders in nonconfined channel.	E′	Channel steps are lacking. Frequent occurrence of knickpoints.
F	Channel generally stable with aggrading floodplain.	F′	Channel degrading with mildly infrequent floodplain deposits. Floodplains undermined and eroded.
G	Water table near surface and increased water storage capacity.	G′	Deep water table and decreased water storage capacity.
H	Abundant vegetation with roots penetrating and stabilizing nearby streambanks.	H′	Little vegetation and roots to protect and stabilize streambanks.
I	Larger late summer streamflows.	I′	Low late summer streamflows.

1963). Generally, swales and slopes were free of incised channels and gullies. Flows also typically carried less sediment. Sustained flow provided a favorable environment for extensive riparian vegetation and supported a beaver population that constructed dams, which further regulated flows. The beaver were likely in dynamic balance with the food supply and predation, and may have expanded the areas supporting riparian vegetation (Parker et al. 1985, Skinner 1986).

Historical misuse of both watershed sideslopes and associated riparian ecosystems throughout the West, in many cases, effectively shifted the balance between watershed condition and riparian health. In many upland areas, widespread overgrazing on rangelands decreased watershed condition by destroying plant cover and decreasing infiltration of water into the soil (Craddock and Pearse 1938, Dortignac and Love 1960, Ellison 1954, Elmore and Beschta 1987, Forsling 1931, Leopold 1946, Rich and Reynolds 1963, Woodward and Craddock 1945). On forested areas, accelerated erosion associated with improper logging practices and road construction during timber harvesting also contributed to unsatisfactory watershed condition. Surface erosion from undisturbed forests was low to nonexistent because enough litter was present on the forest floor to protect the soil surface. Soil permeabilities were normally high (Leaf 1966, Ward and Baker 1984). However, following timber harvesting, surface erosion usually accelerated in response to disruption of soil structure during logging, removal of protective cover, increased raindrop impact and wind movement, reduced infiltration rates resulting from compaction that created overland flow, and the concentration of water by roads, skid trails, and landings (Megahan 1981).

		RIPARIAN HEALTH	
		Healthy	Unhealthy
WATERSHED CONDITION	Good	Very likely	Less Likely
	Poor	Least likely	Very likely

Figure 2.—The likelihood of occurrence of different combinations of watershed condition and riparian health.

In summary, a common scenario leading to destruction of these upland riparian ecosystems was as follows: Grazing or timber harvesting led to a loss of protective plant cover and soil compaction. When removal was severe, infiltration was reduced and overland flow increased. Excessive overland flow delivered more water to the channels where it exceeded channel capacity and resulted in channel enlargement and downcutting. This produced expanded drainage networks that maintained undesirable flashy runoff and increased available sediment. When roads and trails were developed as part of

this use, overland flow was further concentrated and water delivery to the channels increased. Incising channels intercepted and drained existing water tables, many of which were close to the surface and supported healthy riparian ecosystems (fig. 3a). Lowering water tables led to dewatering, alteration and destruction of riparian ecosystems, and an overall reduction in site productivity (Harvey and Watson 1986, Heede 1986, Melton 1965, Schumm et al. 1984) (fig. 3b). Therefore, the resulting attributes of watershed condition and riparian health were quite different (tables 1 and 2). In contrast, on lower elevation mainstreams, woodcutting, agricultural development, urbanization, or more subtle impacts of desiccation from stream incision, impoundment, and channelization, along with overpumping of regional groundwater aquifers, were responsible for the widespread destruction of riparian areas (Conrad and Hutchinson 1985, Cooke and Reeves 1976, Minckley and Rinne 1985).

IMPROVING RIPARIAN HEALTH AND WATERSHED CONDITION

Improving the balance between watershed condition and riparian health requires correctly diagnosing the causes for unbalance and then implementing appropriate rehabilitation treatment plans. Various levels of treatment intensity may be necessary to rehabilitate riparian areas and/or watersheds to restore a desired balance between the two. General approaches for diagnosis, along with specific guidelines for improving riparian health and watershed condition, are presented below.

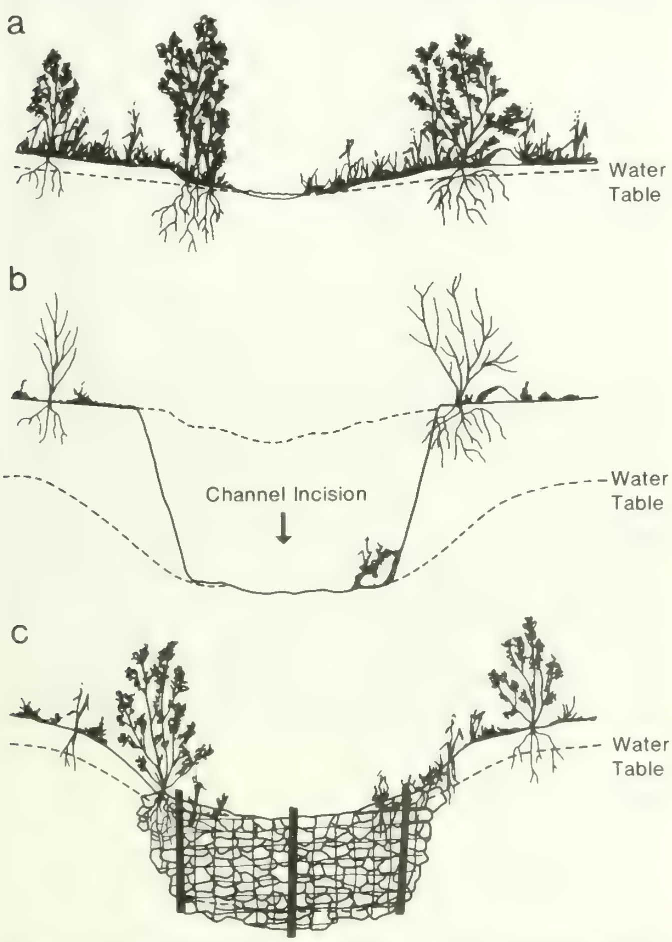

Figure 3.—Water table and riparian vegetation relationships: (a) before channel incision, (b) after channel incision, and (c) following rehabilitation with a channel structure.

Restoring Watershed/Riparian Equilibrium

The balance between watershed condition and riparian health in upland areas is delicate. As a result, it responds readily to both natural processes and human activities. Watershed and land managers have long recognized the need for action programs aimed at rehabilitating misused and deteriorated watersheds (Forsling 1931, Leopold 1946, Lusby 1970, Packer 1953). This awareness led to widespread implementation of watershed rehabilitation projects and programs throughout the western United States (Bailey et al. 1947, DeBano and Hansen 1989, Doty 1971, Hansen and Kisser 1988, Heede 1976, U.S. GAO 1988). The objectives of these projects were primarily to improve plant cover and reduce runoff and erosion by using either revegetation techniques, engineering structures, or both. These treatment measures generally reversed the processes responsible for initially destroying the riparian areas. As a result, these treatments provided a new equilibrium so that the riparian/watershed system could respond to a wider range of storm events and flow fluctuations without producing drastic, or irreversible, changes in the relative balance.

A variety of land treatments and revegetation measures have been applied to deteriorated watersheds to improve hydrologic and hydraulic conditions so existing riparian ecosystems can become stabilized, or new ones created. However, the causes for degradation and stage of channel evolution must be identified before rehabilitation strategies can be developed (DeBano and Hansen 1989, Van Haveren and Jackson 1986). General approaches for providing a more stable riparian/watershed balance are based on two general types of action programs: (1) improving watershed condition on the sideslopes, and (2) stabilizing channels to reduce erosion and downcutting.

These general action programs provide a basis for defining and implementing treatments ranging from simple changes in grazing management, timber harvesting practices, or planting and revegetation activities to more complex measures involving construction of channel structures or mechanical sideslope treatments. However, a careful analysis of cause-and-effect relationships is needed before rehabilitation programs are implemented (DeBano and Hansen 1989, Hansen and Kisser 1988).

Problem identification must also include a careful assessment of both land and channel systems as they relate to current and past land-use practices or catastrophic events such as wildfires. In all cases, the manager must recognize that long periods of time may pass before changes in watershed sideslopes manifest in the channels and associated riparian ecosystem, or vice versa. This is particularly true in the Southwest, where

erosion must be viewed as a discontinuous process that transports sediment from a source (sideslopes) through a channel system with intermittent periods of storage (Wolman 1977).

This episodic transport process is more characteristic of arid and semiarid climates than of humid regions because the prime cause of erosion in the Southwest is the big storm. These big storms move material from various sources, including material stored temporarily in channels, downstream to gaging stations, and other catchments where it can be measured (DeBano 1977). The long lag time between the occurrence of an event on a watershed and sediment delivery downstream has been reported after wildfires in mixed conifer (Rich and Thompson 1974) and chaparral (Heede et al. 1988) vegetation types in Arizona. The impacts of the large events are somewhat tempered if streambank vegetation is healthy because less stream widening and bank erosion occur than if plant density had been reduced by heavy grazing and other land use activities (Platts et al. 1985).

Improving Watershed Condition

A first, and essential, step in restoring the balance between riparian health and watershed condition is to improve watershed condition. Riparian rehabilitation should not be attempted in stream systems where watershed condition is unsatisfactory or in a downward trend (Heede 1977, Van Haveren and Jackson 1986). Rehabilitation treatments range from improvements in grazing management to complex and expensive mechanical treatments such as contour furrows, pitting, and trenches. Often, improved grazing management alone can restore plant cover, but expanded channel networks may continue to erode and transmit unfavorable flows rapidly. This demonstrates the importance of rehabilitating slopes and surfaces (i.e., channel shaping) as well as improving vegetation cover by grazing management or reseeding.

The simplest way of improving watershed condition on rangelands is to provide plants an opportunity for regaining vigor and establishing a denser ground cover. Increasing plant cover allows more water to infiltrate the soil mantle where it slowly moves downslope through the soil before it reappears as channel flow. Proper grazing management is the key to improving plant vigor of rangeland plants.

Where plant cover cannot be improved by grazing management alone, grass seeding and mechanical treatments may be necessary to retain water and aid in vegetation establishment. However, these treatments may require several years of rest from grazing to allow plants to become well established before grazing is resumed. Mechanical treatments of various intensities varying from contour trenches to ripping, discing, and pitting have also been used successfully for improving plant growth and vigor on rangelands. Contour trenching, although a very expensive watershed treatment, has been used to improve high-elevation, deteriorated watersheds throughout the West (Bailey et al. 1947, Copeland 1960). This treatment, however, was unsuccessful when used on steep chaparral watersheds in southern California as an emergency measure to control erosion following fire because the typical storms exceeded the designed capacity of the trenches (Rice et al. 1965).

Contour trenches not only reduce peak flows (DeByle 1970a, Doty 1971), but also increase soil moisture storage immediately beneath the treatment depressions (Doty 1972, Gifford et al. 1978). Infiltration rates into trenches vary considerably, however, depending upon the soil parent material (DeByle 1970b). Reseeding with different native and introduced perennial grasses provides an effective means of stabilizing trenches and improving water uptake. The most successful seeding responses are usually obtained on terrace bottoms (Hull 1973). Upstream treatments on watersheds may not necessarily lead to perennial streamflow but should reduce surface runoff and improve sideslope moisture conditions, which contribute to improved watershed condition.

Maintaining acceptable watershed condition on forested and chaparral areas requires different techniques from those used for rangelands. They will depend, in part, on the degree of disturbance. Activities associated with timber and fuelwood harvesting are most frequently responsible for degrading watershed condition on forested lands (Rice et al. 1972). Minimizing soil disturbance and compaction during logging, along with proper road design and location, are important considerations during timber harvesting. Although the effect of fuelwood harvesting on watershed condition of pinyon-juniper woodlands is not well understood, potential erosion on these areas seems more closely related to herbaceous plant densities and their spatial distribution on interspace areas (Heede 1988). The effect of tree canopy removal during fuelwood harvesting on erosional processes is currently being evaluated.

Watershed condition of chaparral areas is affected primarily by brush-to-grass conversions or by wild and prescribed fires. Chaparral-to-grass conversions may not only maintain acceptable watershed condition, but can enhance riparian plant establishment (DeBano et al. 1984). However, conversions on slopes exceeding 40% are not recommended because of the increased potential for mass soil movement on sideslopes (Rice et al. 1969). Several emergency postfire treatments, including reseeding with annual and perennial grasses, contour planting of barley, contour trenches, and channel checks, have been evaluated on burned chaparral watersheds in southern California (Rice et al. 1965). These treatments were generally ineffective in reducing erosion following wildfires, however, because of the steep sideslopes and channel gradients (Barro and Conard 1987, Rice et al. 1965).

The Role of Channel Treatments in Watershed and Riparian Rehabilitation

Southwestern riparian ecosystems are particularly sensitive to overuse because they are subjected to a wide variation in annual precipitation (Leopold 1946). Surface

streamflow is not perennial in many of the smaller drainages. These marginal streamflow conditions make watershed and associated riparian ecosystems extremely sensitive to overuse, and rehabilitation of deteriorated areas is often complex and difficult. Exclusion from grazing and revegetation measures alone may not be sufficient to fully restore former riparian areas if extensive gullying has dissected ground water tables and caused a general dewatering of the area. This is particularly true in areas where streamflow is no longer perennial. When incised channels are present, additional supplementary measures may be needed. These may include construction of gully structures in upland watersheds (fig. 3c) (Bailey and Copeland 1961; DeBano and Hansen 1989; Hansen and Kisser 1988; Heede 1976, 1977) or channel modification in riparian areas to restore water tables and create stream types with morphological characteristics more desirable for riparian ecosystems (Rosgen 1985).

There are basically two approaches for rehabilitating incised channels: flow control or grade control (Harvey and Watson 1986). Grade control can be achieved successfully on small upland watersheds by installing small channel structures which prevent upstream migration of nickpoints. Although installation of small channel structures is often costly and complex, they have proven effective for stabilizing the channel environment and providing for the recovery of some riparian areas in the Southwest (Hansen and Kisser 1988, DeBano and Hansen 1989, Heede 1977, Heede and DeBano 1984). A recent review of 22 successfully rehabilitated riparian areas throughout the western United States showed that 11 projects used in-stream structures, bank riprap, or a beaver dam (U.S. GAO 1988). The remainder were rehabilitated primarily by grazing management in riparian areas.

Case Studies

Constructing check dams in channels has converted ephemeral, or intermittent, streamflow to perennial in several case studies throughout the western United States (DeBano and Hansen 1989, Hansen and Kisser 1988, Heede and DeBano 1984, Stabler 1985). Check dams, which are small, porous channel structures, can be used for this purpose. These check dams can be constructed of soil, concrete, rock, wood, sheet metal, or several other materials (Heede 1960, 1976).

The effect of small channel check dams on riparian enhancement is well illustrated by a gully rehabilitation program initiated in 1958 on the 640-acre Alkali Creek Watershed located in the White River National Forest, about 20 miles south of Silt, Colorado (Heede 1977). Vegetation on the watershed is sagebrush-grassland typically found on the western slopes of the Rocky Mountains in Colorado. Gambel oak occupies the upper parts of north-facing slopes, while sagebrush and grass make up valley bottoms, depressions, and south aspects. (Plant species' scientific names, authority, and common names are presented in appendix B.) Annual precipitation averages about 19 inches, of which approximately 40% occurs as rain between May and September and 60% as snow during the rest of the year. Valley bottom soils are sodic and contain higher percentages of clay, reflecting alternate layers of sandstone and shale in the underlying parent materials (Heede and DeBano 1984).

Grazing, first started on the watershed in the 1870's, was excessive and resulted in destruction of plant cover which led to overland flow, concentrated channel flow, soil piping, and gully formation. Extensive gully systems, with deeper gullies exceeding 50 feet, were present throughout the watershed before rehabilitation treatments were initiated. Before treatment, streamflow was ephemeral, occurring only during snowmelt periods (Heede 1977). The area was fenced in 1958, and grazing was excluded between 1958 and 1966. Active gully treatment was started in 1961 with the objectives of (1) rehabilitating the depleted watershed by vegetative and engineering measures, (2) testing their combined effectiveness on restoration, and (3) developing new treatment approaches where required. The main treatments consisted of constructing 132 check dams, developing vegetation-lined waterways (1,900 feet), and follow-up vegetation management.

The response of the watersheds to gully treatment, revegetation, and exclusion from grazing was dramatic. During the 12 project years, the check dams accumulated 2,556 yd^3 of sediment, gully depth was substantially reduced, and erosion rates were reduced to one-fifth of those on gullies not structurally treated (Heede 1977). The hydrologic regime at Alkali Creek was also changed. Before treatment, streamflow occurred only for about 6 weeks during snowmelt periods. Seven years after treatment, flow discharge was perennial at the watershed mouth, but remained ephemeral in headwater areas of the gully network.

In the upper watershed, duration of streamflow was not extended sufficiently to allow riparian plants to become established. However, grass production increased on sediment deposited in the upper structures although the beneficial effects were limited to grass established in the channels (fig. 4). In contrast, streamflow regime in main channels on the watershed was significantly improved so that a riparian plant community became established (fig. 5). The hydrologic regime in the main channels was improved by a rising water table, resulting from the additional storage of water in sediments deposited in channels above the structures and adjacent gully walls. The stored water was released slowly over time as unsaturated flow (Hewlett and Hibbert 1963) and produced perennial, or near perennial, streamflow. This principle has been used successfully worldwide as a means of artificially recharging subsurface water storage during heavy rainfall periods with "trap-dams" (Baurne 1984).

Prolonged streamflow at Alkali Creek allowed sedges and willows to become established, which enlarged into a dense riparian ecosystem by 1981 (fig. 5c). After the channel bottoms had become stabilized, riparian vegetation spread to the toe and lower segments of the gully sideslopes. Sediment deposits above the check dams prevented undercutting and loss of bank toes, and pro-

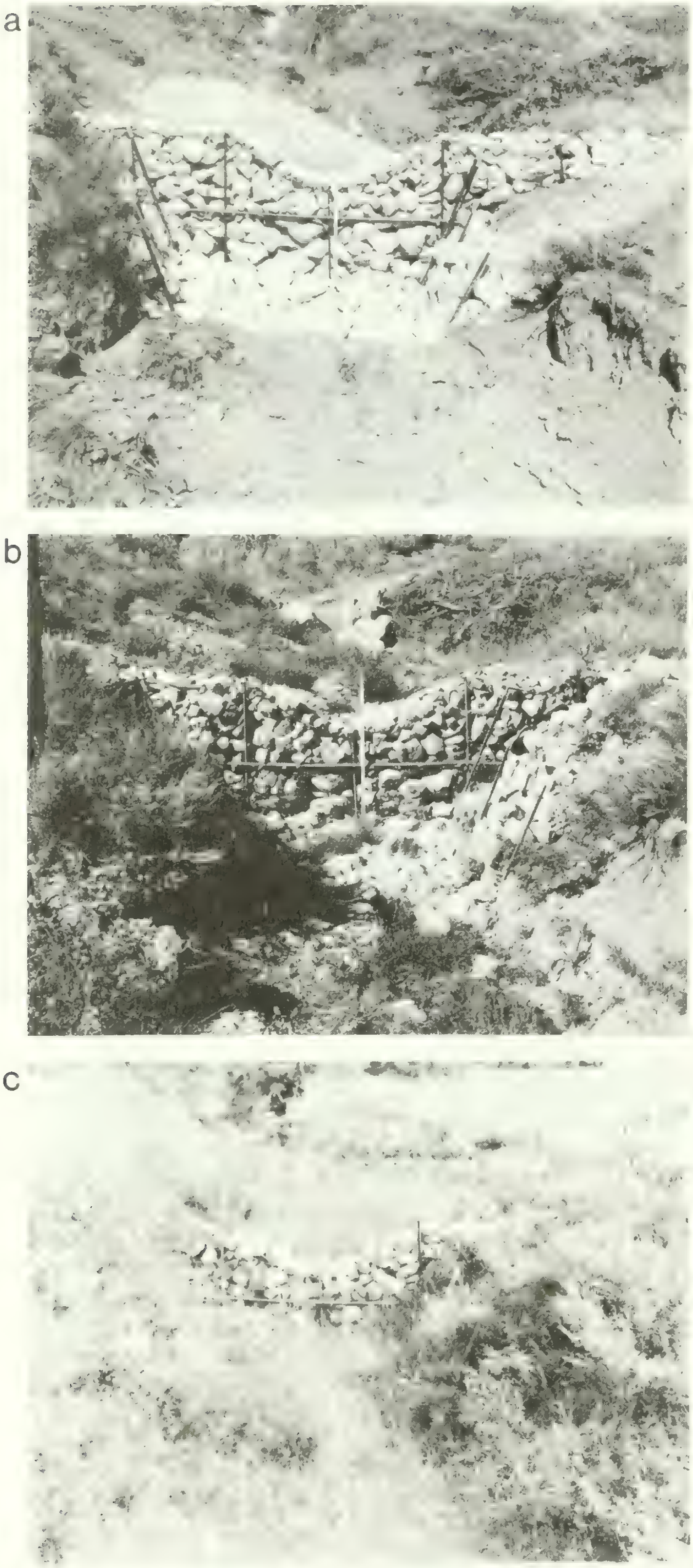

Figure 4.—An upstream view of a rock check dam constructed in an upper watershed channel on Alkali Creek in western Colorado: (a) immediately after construction in 1963, (b) in 1964, and (c) 12 years later in 1975. Notice the establishment of grass on channel banks and bottoms but the absence of riparian plants.

Figure 5.—The appearance of the site occupied by a larger gully control structure at the mouth of Alkali Creek in western Colorado: (a) immediately after treatment in 1963, (b) in 1964, and (c) 12 years later in 1975.

vided the base-level stability necessary for establishing riparian species. The size of gully check networks necessary to store enough water to sustain perennial streamflow depends on local soil and climatic conditions; 132 structures trapped sufficient sediment and water to enhance riparian establishment and development by natural means in the main channels under the prevailing climate at Alkali Creek.

Not only did the hydrologic regime of the watershed improve, but sediment accumulating in channels provided a better medium for plant growth than eroding sideslope material. Much of the eroding sideslope material originated from high-sodium soil lenses (exchangeable sodium percentage greater than 16). It took several years before enough sodium was leached to allow plant growth (Heede 1971). In contrast, sediment deposited in channels had ESP values of less than 1 (Heede and DeBano 1984), which was more favorable for plant growth.

Effect on Channel Dynamics

A well-designed network of channel checks in a watershed can have positive effects on channel dynamics. First, where ample sediment is available, small structures, such as check dams and small earthen gully plugs, withhold only a small portion of the total sediment. Therefore, the sediment load in the streamwater leaving the structure is sufficiently high to prevent it from picking up any large amount of additional sediment. A second important feature of check dams in gullies is that they are often at a designed spacing that transforms turbulent flow into a more tranquil flow with lower energies (DeBano and Heede 1987). The combined result is a stable channel with a static or aggrading base level, which provides a more favorable habitat for riparian ecosystems both upstream and downstream. If riparian vegetation encroaches on check dams and seriously diminishes the flow capacity of spillways, however, then flows may overtop the dam's freeboard or create end cutting of structures. These flows can erode gully banks and, over time, create new gullies around the structure, resulting in destruction of both the dam and associated riparian ecosystem.

Maintenance and Upkeep

An important consideration when developing treatment plans for watershed rehabilitation is to be aware of their effect on upland channel dynamics, and to include provisions for maintaining these structures under different channel equilibrium conditions (DeBano and Heede 1987). This is particularly important when riparian rehabilitation depends upon expensive and complex treatments, such as tributary channel structures. Spillway stability and integrity of structures should be examined regularly and appropriate repairs made immediately to weakened or damaged structures (DeBano and Hansen 1989). Applying good range and forest management principles in conjunction with channel structures is also a prerequisite for long-term success. This requires applying livestock management methods and stocking levels compatible with watershed and riparian improvement objectives as a whole. These have proven vital to the health and success of newly established riparian ecosystems.

Guidelines for Improving Watershed Condition and Riparian Health

The large body of information on watershed rehabilitation and riparian health described above provides a substantive basis for better understanding the delicate balance between the two, and provides the principles necessary for formulating general management approaches and specific treatment plans for successfully planning riparian area rehabilitation programs. This section summarizes this background information within the framework of the conceptual model in figure 1 and then uses this model as a basis for (1) diagnosing the causes for lack of balance between riparian health and watershed condition; (2) developing objectives for alternative treatments; and (3) specifying treatments necessary for restoring an acceptable balance between watershed condition and riparian health.

Various land uses and misuses affect the balance between watershed condition and riparian health by creating (1) excessive runoff, (2) increased frequency and magnitude of stormflow events, (3) excess discharge, (4) excess stream slope, (5) excess tributary sediment, and (6) excess bank sediment. Substantial permanent changes in watershed condition tip the equilibrium indicated in figure 1 in one direction so no oscillation about the mean occurs. This causes an adjustment in erosion and deposition processes to proceed in the direction indicated by the indicator arrow until a new dynamic equilibrium is established. Once achieved, a new dynamic equilibrium is maintained until new changes exceed the elastic limit of the system, setting the process of adjustment in motion again.

After the factors responsible for disrupting the initial balance between watershed condition and riparian health have been identified, their causes can be used as guiding principles for formulating specific treatment objectives and remedies (table 3). The large array of possible treatment alternatives can be classified into two general types: those used for (1) improving vegetation cover and reducing surface runoff and erosion from sidelopes; and (2) stabilizing channel networks. Four broad alternative courses of action arise from these two general approaches. One alternative is to do nothing. This alternative would usually not be acceptable to managers where riparian/watershed systems are out of balance. The remaining three alternatives require different levels of action programs. A second alternative may involve only managing, or treating, sideslopes. Sideslope treatment would be feasible on those watersheds where naturally occurring control sections (bedrock) are present. Bedrock exposed by channel erosion

Table 3.—Conditions threatening riparian areas and possible remedies for achieving different treatment objectives

Condition	Cause	Remedy	Treatment objective
Excess runoff	Major flood events on pristine watersheds.	None on watershed. If riparian areas have been damaged, then some structures, bank stabilization, and revegetation may be necessary.	Rehabilitate changes.
	Areas with depleted cover lacking infiltration capacity and resistance to surface runoff.	Improve livestock, game, or fire management. Revegetate and manage for increased vegetation and litter cover.	Increase resistance to surface flow. Greater infiltration capacity. Eliminate sheet runoff.
Increased frequency and magnitude of flow events.	Rilled and gullied slopes resulting from depleted cover or soil compaction.	Reduce drainage density by constructing contour furrows or trenches and manage for increased ground cover. Restoration of vegetation.	Increase retention of storm flow on-site until infiltrated. Eliminate concentrated flow. Regulate runoff through soil mantle. Increase vegetation cover and improve infiltration.
	Roads and travelways that intercept, collect, and concentrate flows.	Intercept flow paths with waterbar and divert flows to areas with greater infiltration capacity. Rip and reseed compacted surfaces where travelways have been abandoned. Improve forest filter by adding log flow obstructions or detention basins. Eliminate traffic.	Shorten slope length. Infiltrate excess flow into forest floor. Restore on-site infiltration of flow and protect soil. Regulate flows through soil mantle.
Excess discharge	Transbasin diversion that produces the effect of greater drainage area and increased flow.	Provide reservoir storage to regulate transferred flows. Avoid inchannel transport of increased flows. Convey increased flows during low-stage seasons.	Maintain flows within the limits of critical stream power.
	Forest harvest effects on water yield that produce greater runoff.	Schedule harvests in time and space over the watershed to maintain increased runoff within the range of channel capacity and critical power. Consider effects of various silviculture techniques on snow retention and water yield. Minimize road density and drainage of lower slopes by roads	Maintain flows within critical power threshold. Dissipate peak flows through soil mantle.
Excess stream slope	Channelization of riparian areas by roads, trails, and travelways.	Avoid roads, trails, and travelways in riparian areas. Eliminate old travelways and relocate where necessary. Take special precautions and measures to avoid channelized flow where facilities must be in riparian areas	Maintain slope, channel length, and configuration that support dynamic equilibrium. Avoid actions that concentrate flows, produce higher velocities, or change energy configuration of channels or meadows.
	Historic channelized riparian caused by arroyos, gullies, and travelways.	Reestablish and construct channel configuration and slope that watershed conditions can sustain (Heede 1968a) or use check dams to control grade while channel adjusts to new equilibrium. Where conditions allow, consider introducing beaver.	Develop slope channel length and configuration that supports a new dynamic equilibrium. Correct conditions that generate unfavorable flows.
	Absence of large organic debris to provide steps and energy dissipation in confined mountain channels.	Add logs or rock structures to regain stability. Manage adjacent areas to provide a desired rate of logs to the system.	Reduce streamslope with log steps or other structures. Slow velocities, reduce flood peaks, and increase channel uptake. Stabilize sediments.
Excess tributary sediment	Sheet and rill erosion from denuded areas.	Apply techniques similar to those used for controlling excess runoff.	Reduce exposure to erosion. Eliminate concentrated flow on slopes. Provide vegetation protection.
Excess bank sediment	Incised, confined channels that cut high banks.	Improve watershed condition. Reduce bank heights by installing check dams. Use flow separation techniques to deposit materials to buttress banks and provide a media for riparian vegetation establishment. Use techniques outlined for excess slope.	Reduce availability of sediment. Restore channel equilibrium that can be sustained.

may be currently limiting future downcutting. Under this alternative, if rilling and gullying have not occurred, then sideslope management alone may allow a dense vegetative cover to become established. Where surface rilling and gullying are severe, channel shaping, contour trenching, and revegetation may all be required. Techniques for channel shaping and revegetation are described by Heede (1968, 1975). The primary objective of these treatments is to enhance the natural healing processes, revegetate channel banks, and reduce sediment contributions from bank erosion. It is unlikely riparian ecosystems would be established in response to this treatment alternative because former water tables necessary for riparian rehabilitation have not been restored.

A third, more complex, alternative might involve channel stabilization. This alternative should be attempted only where watersheds are healing naturally as a result of improved management, but require assistance in stabilizing base control sections. The objective of this treatment could be to stabilize or stop downcutting, reduce erosion, and revegetate channel banks. Channel structures, such as check dams, would be constructed to control base levels. Dam spacing and effective spillway heights would be designed not only to store enough sediment to stabilize the channel but to stabilize sideslopes. Successful revegetation of sideslopes depends upon establishing bank stability, which in turn depends on bank height and angle (Grissinger and Bowie 1984), soil shear strength pore pressure relations (Bradford and Piest 1977), and soil particle cementation (Goss 1973). Approaches to gully treatment (Heede 1968, 1976, 1978), computer procedures for gully control (Heede and Mufich 1973, 1974), methods of construction (Heede 1960, 1965, 1966, 1968), and strategies for determining treatment priorities (Heede 1982) are all available in the literature. Water storage and ground water recharge are minimal with this level of treatment and, consequently, enhancement of riparian ecosystems would be limited to a few structures in the main channel of the watershed (DeBano and Heede 1987).

Finally, the fourth, and most comprehensive, treatment alternative involves both channel stabilization and comprehensive watershed rehabilitation (Heede 1977). The objective of this level of treatment would be to stabilize and aggrade channels, and provide adequate channel and ground water storage to encourage the establishment of riparian ecosystems. Channel deposition and ground water recharge would be increased by increasing dam spacing and effective spillway heights. The resulting channel aggradation would provide water storage behind each structure, and improve soil moisture and channel flow. Riparian establishment could occur naturally or be enhanced by planting species adapted to the area.

Any combination of the last three levels of action plans described above may be implemented within a single watershed, but it remains critical to establish treatment objectives first. Although it is possible to enhance or rehabilitate potential riparian areas with these treatments, it is important that continual management and maintenance be included as an integral part of these rehabilitation plans in order to maintain the effectiveness of the initial treatments.

Synopsis

There are important and sensitive hydrologic relationships between watershed condition and the health and integrity of associated riparian ecosystems throughout the Southwest. However, extensive management activities and natural events in the past drastically altered the balance between watershed condition and riparian health. Vegetation removal and soil compaction substantially increased surface runoff, produced sediment-laden flows, and increased erosive power in the channel system. This led to the degradation and destruction of many riparian areas. A key factor in improving deteriorated riparian areas is understanding the balance that existed between watershed condition and riparian health in near pristine conditions when watershed slopes and riparian channels could dissipate rainfall and concentrated flow energies produced during a wide range of precipitation events.

Land managers are currently implementing a variety of watershed treatments that are, or have the potential for, rehabilitating riparian ecosystems. In some cases, these treatments were initiated for other reasons than improving riparian areas. These treatments increased both duration and/or amount of streamflow. The most obvious practices benefiting riparian areas are upstream treatments aimed at improving watershed condition, lengthening duration of streamflow, reducing peak flows, and stabilizing channels to reduce erosion. Watershed condition may be improved by better livestock management and more judicious road construction during timber harvesting, although sometimes these improved management practices must be supplemented with specific cultural treatments, such as reseeding and tree planting to increase plant cover and vigor. Extremely disturbed watersheds with substantial amounts of rill erosion and channel incision may require strategically located channel structures, bank stabilization, and mechanical treatment of sideslopes to be successfully restored. However, when developing any rehabilitation plan, it must be kept in mind that not all incised channel networks are candidates for channel structures, because (1) some may heal on their own over time; (2) the value of rehabilitation may not justify the cost; or (3) the systems are too dynamic to allow structures to be safely installed.

Successful rehabilitation programs require having a clear picture of the desired balance between riparian health and watershed condition and what caused the current problems. The basic knowledge for improving both watershed and riparian areas is generally available. However, the key to successful rehabilitation lies in wise and timely application of management principles and technology.

Riparian areas are linear in form and thereby serve as key corridors for transporting water and erodible material derived from the surrounding landscape (Brinson et

al. 1981). Because of this, the management techniques described above for enhancing riparian vegetation has some risk; their limitations must be recognized before implementing different treatments. Of particular concern is the effect of these different management strategies on mitigating the erosive power of streamflow characteristics and associated channel dynamics.

WATER AUGMENTATION AND RIPARIAN ENHANCEMENT

Cover Manipulation and Water Augmentation

Vegetation cover manipulation has been studied as a potential management practice for augmenting water yield throughout the Southwest (Ffolliott and Thorud 1974, Hibbert 1979). These practices are based on the premise that replacing plant species having high water use demands with lower water-demanding plants will decrease total evapotranspiration, thereby making more of the annual precipitation available for streamflow.

Increased water delivery to downslope channels in response to upslope vegetation manipulations have been studied for the four major vegetation types in the Southwest—chaparral (Hibbert et al. 1974), pinyon-juniper (Baker 1984), ponderosa pine (Baker 1986), and mixed conifer (Rich and Thompson 1974). Cover manipulations in mixed conifer and ponderosa pine forests mainly involve timber harvesting. Trees are removed from pinyon-juniper woodlands during both fuelwood harvesting and range improvement programs. Brush-to-grass conversions have been proposed as a technique for increasing water yield in Arizona chaparral, although grass forage production is also increased and fire hazard reduced.

Total annual streamflow is increased in all four vegetation types, although the timing and amount of increased water production varies (Hibbert 1979). Duration of streamflow is also significantly increased by brush-to-grass conversions in chaparral (Hibbert et al. 1974). These increases in duration and amount of streamflow have strong implications both for watershed condition (cover on upland slopes is being altered) and riparian health (because of increased amount and duration of streamflow).

Case Study

The effect of brush-to-grass conversions on water augmentation and enhancement of downstream riparian ecosystems was evaluated on the Three-Bar watersheds in central Arizona (DeBano et al. 1984).

The Three Bar experimental watersheds, near Lake Roosevelt in central Arizona, were established for studying the effect of shrub control on water yield in chaparral. Elevation of the Three Bar watersheds varies from 3,280 to 5,120 feet. Mean annual precipitation ranges from 21 to 28 inches. Soil parent material is a coarse granite. Exposure is northerly. The upper slopes of the watersheds are steep, often exceeding 60% (Hibbert et al. 1974). Dominant shrubs on the Three Bar watersheds are shrub live oak, birchleaf mountainmahogany, sugar sumac, and Emory oak. Streamflow and rain gages were installed in 1956. At that time, streams draining the watersheds were ephemeral, flowing about one-third of the time during the initial 3-year calibration period and yielding, on the average, less than one surface inch of water annually. In June 1959, a wildfire topkilled the shrubs on all watersheds. Shrub cover, which was 60% to 75% before the fire, was reduced to near zero.

Two of the four experimental watersheds at Three Bar were used for assessing the effect of brush control on streamflow and riparian area enhancement—control watershed (D) and a treated watershed (C). Beginning in 1960, watershed C received a series of herbicide treatments aimed at eliminating a dense stand of shrubs. Watershed C was seeded in May 1960 with lovegrasses. By 1969, shrub crown cover on watershed C had been reduced to less than 3%. However, the reseeded lovegrasses formed a dense cover on Watershed C that was intentionally burned in 1971, 1974, and 1978 to keep the invading shrub cover to less than 10%. After the 1959 wildfire, watershed D (88 acres) was allowed to recover naturally as a control. Sprouting shrubs regained about one-third of their prefire crown cover in 3 years and about 90% in 11 years (Hibbert et al. 1982).

Streamflow increased substantially after brush conversion on all treated watersheds (Hibbert 1971). The increases were largest for watershed C, which yielded about 6 surface inches more water per year than expected without treatment. Runoff represented a larger percentage of precipitation in wet years than during dry years for both treated and control watersheds because more water was available for streamflow.

Not only was streamflow volume increased by treatment, but also duration of streamflow during June, July, and August was lengthened dramatically (DeBano et al. 1984). Before the 1959 wildfire, both watersheds C and D experienced long periods without streamflow. From 1957 to 1959, the average period of no streamflow was 76 and 74 days for watershed C and D, respectively. After the wildfire, streamflow from watershed C became perennial and has remained so to date, because herbicide treatments reduced shrub evapotranspiration losses enough to maintain streamflow. In contrast, streamflow from watershed D varied widely. In some years flow was perennial, while in other years there were up to 91 continuous summer days with no streamflow. Streamflow from watershed D was perennial from June through August only when antecedent precipitation exceeded 22 inches. Watershed C maintained perennial flow regardless of the antecedent precipitation, although less occurred during drier years.

Within 5 years after the wildfire, differences in the number of riparian trees and shrubs in the channel below watersheds C and D reflected the difference in streamflow regimes (fig. 6). Before the fire in 1956, riparian species were absent below the gaging station on watershed C (fig. 7a). Immediately after the fire in 1959, the gaging station was devoid of all vegetation. By 1973, large

cottonwood trees had become established (fig. 7b). By 1983, the stream reach immediately below the gaging station supported a dense stand of willows, cottonwoods, and other species (fig. 7c). In contrast, below the control watershed D few riparian plants were present by 1983. Common riparian species below the gaging station at 3-Bar C were Gooding willow, red willow, and Fremont cottonwood. Smaller numbers of Arizona walnut and broom baccharis were also found in the stream channel below watershed C but not below watershed D.

It might be questioned whether enhancing riparian vegetation reduced the increased water yield sought by the original treatments. Previous research established that about 85% of the increased water yield is produced during the dormant season (November-April), which benefits the delivery of water downstream (Hibbert et al. 1982). Thus, it was concluded that establishing narrow stringers of riparian vegetation at the mouth of watershed C would have little impact on downstream water yield increases produced by upslope shrub control.

The chaparral-to-grass conversion treatment on the 3-Bar C watershed had mixed effects on bird populations (Szaro 1981). Although population density, species richness, and diversity of bird populations increased in the riparian area, these indices were lower for the grasslands compared to the original stand of chaparral.

Recent studies on chaparral conversions have shown similar water yield increases can be obtained by chaparral-to-grass conversions in a mosaic pattern where only about 60% of the brush is treated and replaced with grass (Hibbert and Davis 1986). The remaining 40% of the brush can be left in strategic locations to protect steep slopes from erosion, maintain desirable plant species, and provide habitat diversity for wildlife.

Synopsis

Vegetation cover manipulations, particularly brush-to-grass conversion in chaparral, offer a viable technique for both increasing and lengthening streamflow, thereby enhancing the establishment of downstream riparian areas. These conversions, when carefully planned, will probably not produce any long-term change in watershed condition (increase erosion, reduce plant cover, etc.).

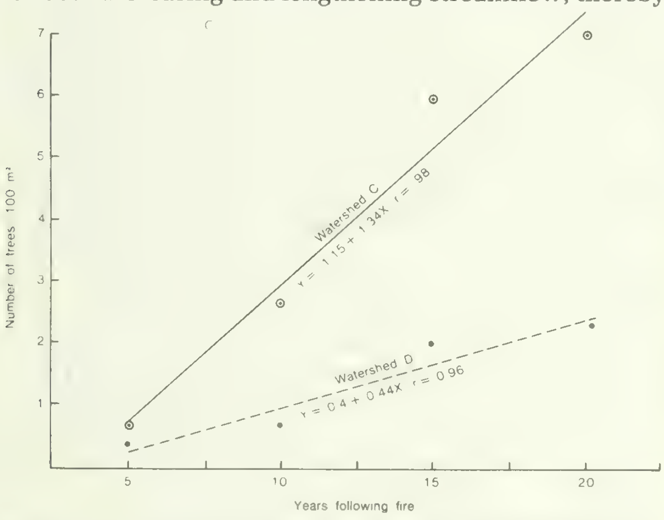

Figure 6.—The number of riparian tree species established below a chaparral watershed treated for shrub control (C) and on a nearby untreated watershed (D) (DeBano et al. 1984).

Figure 7.—The appearance of the stream reach immediately above and below the gaging station at Three Bar C: (a) before a wildfire in 1956, (b) in 1972, and (c) in 1983. Riparian invasion was removed regularly above the gaging station to prevent interference of trees and shrubs with streamflow measurements.

The greatest potential increase in annual streamflow per acre treated can be obtained by harvesting timber in mixed conifer because this vegetation type receives the greatest amount of annual precipitation (Hibbert 1979). Substantial increases also occur during timber harvesting in ponderosa pine. In both these commercial forest types, however, water yield increases resulting from the effect of timber harvesting on snowmelt occur mainly during spring when water use by riparian plants is lowest. Duration of streamflow is not changed substantially by timber harvesting in either ponderosa pine or mixed conifer forests. In southwestern pinyon-juniper woodlands, only small increases in water yield can be obtained by tree removal (Baker 1984), making it unlikely the treatment of pinyon-juniper woodlands would produce enough additional water to enhance riparian ecosystems.

In the final analysis, it appears brush-to-grass conversion in Arizona chaparral is a promising management tool for enhancing riparian areas, because it not only produces the second largest increase in water yield per acre treated, following mixed conifer, but also increases streamflow duration significantly (Hibbert et al. 1974). Brush-to-grass conversions also reduce fire hazard and increase wildlife habitat diversity in the riparian area itself. However, care must be exercised so that existing riparian communities in untreated chaparral are not endangered by the treatment (see the case study at Monroe Canyon under intermediate structures presented later). Also, it is important to note that grasslands produced during a brush-to-grass conversion, particularly when reseeded with aggressive exotic grasses, may have lower bird population densities, species richness, and diversity than the former chaparral cover. However, judicious chaparral conversion projects producing a brush-grass mosaic pattern appear to be a viable management strategy for enhancing the hydrology of riparian areas while, at the same time, maintaining water yield increases and habitat diversity.

THE ROLE OF IN-STREAM CHANNEL STRUCTURES IN RIPARIAN HYDROLOGY

Many principles established during the earlier discussion on gully rehabilitation also hold true for larger man-made channel structures and for various-sized natural structures. For example, duration of streamflow can be lengthened with both naturally occurring and man-made channel structures. Natural channel structures consist of fallen logs imbedded in the stream channel (log steps), large boulders, beaver dams, accumulations of large woody debris, and cienegas. Man-made structures include large flood control structures, intermediate-sized erosion control dams, and the small check dams (gully plugs) discussed earlier.

All channel structures capture and immobilize some sediment. However, they may vary in their capacity to regulate flow. Cienegas and large flood control structures both pond ground water and store sediment, whereas small check dams mainly store sediment and reduce flow energies. Although man-made structures may not necessarily store surface water, they provide temporary channel storage of flood waters, which affects the timing and duration of streamflow through downstream reaches. The improved hydrologic regime created by channel structures not only improves riparian habitat but also has implications for managing in-stream flows (Van Haveren 1986).

Small channel structures are most important on low-order streams in upland watersheds where riparian ecosystems consist of small stringers of trees and brush occupying the channel and banks in the immediate vicinity of the stream. In contrast, downstream riparian ecosystems associated with larger channel structures occupy extensive floodplain areas along larger order rivers passing through lower elevation desert environments.

Naturally Occurring In-Stream Channel Structures

Several types of channel structures created by naturally occurring processes can create environments favoring establishment of riparian ecosystems. The most important natural structures are cienegas, log steps in smaller streams, debris accumulation in larger streams, and beaver dams.

Cienegas

The term cienega was coined by Spanish explorers in the southwestern United States to describe riparian marshlands (Hendrickson and Minckley 1985). Cienegas are mid-elevation (3,300-6,600 feet) wetlands characterized by permanently saturated, highly organic, reducing soils. The flora is dominated by low sedges that are highly adapted to soil characteristics found in these habitats.

Under natural conditions, cienegas evolve after the soils in an area have passed through a series of aggradation and degradation steps following channel obstruction (Hendrickson and Minckley 1985, Melton 1965). Obstructions can occur because of slow uplifting or intrusion of bedrock across a drainage channel, which may span thousands of years, or in other cases, occur quickly as during catastrophic events such as earthquakes (Mackintosh 1984). Very active first- and second-order tributaries may deposit coarse material as alluvial fans and obstruct channels in higher order, steep-walled drainages. These alluvial fans effectively act as channel controls that reduce slope gradients and encourage deposition of materials. Also, sediment deposits and subsequent sinuous channel forms favor riparian ecosystems. Similar channel controls result from mud-rock flows and landslides that add more material to the channel than it has stream power to remove. These geomorphic features provide the macro-controls which, along with input of ground water from regional aquifers (Jackson et al. 1987), initiate cienega formation. Subsequent ponding of alluvial ground water and trapping of sediment initiates riparian plant establishment and succession.

Vegetation establishment on the cienegas, combined with their relatively flat topography, effectively dissipates energy and fosters sediment and organic matter deposition which, in turn, improves infiltration of water. Over time, a diverse riparian ecosystem becomes established and is maintained unless subjected to severe disturbance. Ultimately, these deposits are sustained by the cienega vegetation at slopes that are highly vulnerable to concentrated flows or other small alterations in the form, or cover, of the cienega. Under these conditions, linear perturbation such as trails, or breaks in plant cover, can cause rapid downcutting and eventual destruction of the cienega. Major deposits of sediment from tributaries can also trigger a series of discontinuous headcuts that ultimately lead to dewatering of the cienega.

Streamside Vegetation and Organic Debris Accumulation

Forest and riparian plant communities along small streams act as both erosion buffer strips (Heede 1988) and nutrient filters (Cooper and Gilliam 1987, Lowrance et al. 1984c). In upland areas, these plant communities can affect the streamflow hydraulics and channel dynamics of small mountain streams (Heede 1985a, 1985b; Megahan 1982; Swanson et al. 1984). This occurs when trees and logs fall across the channel and are incorporated into the hydraulic geometry of the stream channel, creating log steps (figs. 8a and 8b) (Heede 1981). When this organic debris accumulates on the streambanks, it improves channel stability by promoting soil development, increasing infiltration, and reducing overland flow and bank erosion. The log steps in the stream channel accumulate sediment, thereby reducing the channel gradient and improving channel stability. Waterfalls then develop over each step which further reduces flow energies substantially (fig. 8c). When log steps are submerged during high flows, they contribute to the channel roughness and further decrease flow velocities. In natural systems, these log steps rot and are eventually replaced by newly fallen limbs and trees in order to maintain dynamic equilibrium. While these log steps are in place, they store sediment which would otherwise be lost downstream. As a result, these log steps and other debris accumulations provide a mechanism for enabling alluvial deposition and the formation of alluvial aquifers, which encourage the establishment of riparian vegetation along these small upland streams in the Southwest.

Large-particulate organic debris accumulations in channels also play an important role in maintaining riparian ecosystems along the larger, low-elevation rivers of the Southwest (Minckley and Rinne 1985). In this desert stream environment, large accumulations of debris function as sources of nutrients and also provide a quasi-stable environment in an otherwise unstable system. However, riparian ecosystems can become so dense that they fully occupy the channels and cause flooding, as has been reported along the lower elevation reaches of the Salt and Gila Rivers in Arizona (Graf 1980).

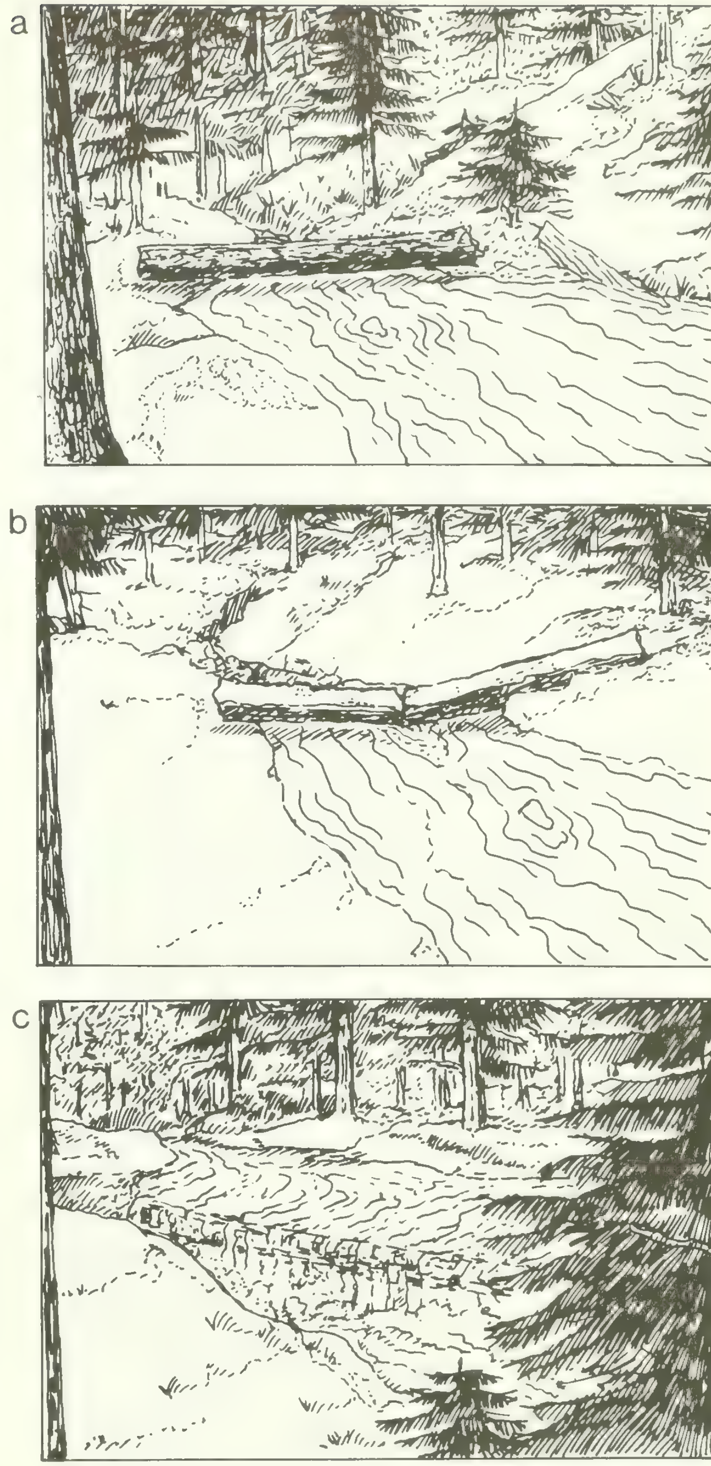

Figure 8.—Log steps form when a log falls across a stream (a) and becomes incorporated into the channel geometry (b) where it effectively acts as an energy dissipator (c) (Heede 1981).

These riparian areas formerly supported stands of willows, cottonwoods, and mesquite bogs, but have recently been replaced with dense stands of saltcedar. The former riparian species were removed for fuel and lumber during settlement of Arizona. Currently, several thousand acres of former riparian areas are covered with saltcedar. Although the establishment of a new habitat

has benefited some wildlife populations, it has caused serious flooding problems that have invoked legal, institutional, and economic concerns (Graf 1980).

Beaver Dams

Beaver dams also create favorable channel environments for riparian ecosystems (Parker et al. 1985, Skinner 1986). These dams usually extend fully across a channel and act as a very wide weir during flood peaks, which affects the hydraulic regime in at least two ways. First, flood waters are spread over a wider area, which reduces the hydraulic head. This changes highly turbulent flow into more tranquil flow, which decreases the erosional energy of flowing water. Secondly, peak discharges during runoff events may be dissipated, because these dams have some water retention capacity. The dams can also improve water quality by reducing the concentrations of suspended solids, total nitrogen, and total phosphorus (Parker et al. 1985). The retention of sediment and nutrients, as well as the level valley geometry, both encourage long-term cienega formation and establishment of riparian ecosystems.

Beaver dams need special consideration because they are built according to different engineering standards than man-made structures, and are dependent upon stable beaver populations (DeBano and Heede 1987). Beavers build level dams simulating very wide weirs which limit flow heads and velocities at high volume flows. As a result, the dams have much less concentrated flow to deal with compared to typical man-made structures that have a single spillway which constricts flow. Beavers also initially tend to build dams in a downstream to upstream direction because they need ponded water to provide a means of transporting material to the next dam site in safety. This often produces a plunge pool immediately below successive upstream dams. These two factors largely eliminate the need for a splash apron and back protection below the structure which are typically required in man-made structures.

The upstream construction pattern captures sediments that render downstream dams less effective for beaver habitat. It also creates a system where previous channels become ambiguous and produce a very sinuous pathway for streamflow. The lower slopes and energies may allow a new channel equilibrium to develop that differs substantially from the previous pattern.

Beaver dams are stable on watersheds in good condition where beaver populations are also stable. When animals are removed from a given stream reach, as occurred during the 1840's (Quaife 1930), the dams are no longer maintained. The removal of the beaver populations coupled with exposure to flashy flows can remove all dams in a domino-fashion because often, when one beaver dam is lost, all downstream dams will also be demolished due to developing water-sediment surges. Flow and sediment surges, fed by extensive water and sediment accumulations in the beaver ponds, can cause extensive channel damage. Failure of dams causes a loss in stored ground water, and riparian ecosystems collapse. As a result, it appears beaver dam upkeep, or replacement by a human version, must be part of effective beaver dam management. Upkeep requires maintenance of a balance between existing structural material for dams, food supply, and animal numbers.

Beavers should be introduced, or reestablished, for improving riparian areas, but only where adequate food sources are available. For example, where there is little or no riparian vegetation and trees are widely scattered, it may be necessary to control beaver populations so that the struggling riparian vegetation can become established and provide an adequate food supply.

Synopsis

Land managers need to be aware of the opportunities for riparian improvement provided by naturally occurring mechanisms. The most common are log steps, cienegas, and beaver dams. Log steps and streamside vegetation on smaller upland streams and watersheds play an important role in regulating both streamflow and nutrient fluxes from these watersheds and, as such, provide an essential moderating link between the watershed and the associated aquatic and riparian ecosystems. Log steps in channels also act as effective natural energy dissipators, and their regular replenishment must be considered when planning timber harvesting or other management activities.

Cienegas created by natural geologic processes pass through several evolutionary stages, some of which are more susceptible to damage than others. As the slopes sustained by cienega vegetation become steeper, they are more vulnerable to linear perturbations such as trails, or breaks in plant cover, which can lead to irreversible damage to these important riparian areas.

Beaver management provides an additional tool for improving riparian areas. Beavers dams, unlike man-made structures, are self-maintaining and are able to accommodate "natural" channel adjustment. However, limited food supplies and increased predation can reduce beaver populations so that dams are no longer maintained and riparian ecosystems are lost.

Although riparian ecosystems usually have beneficial effects, conditions can develop in larger streams at low elevations where excessive plant growth plugs channels and produces unwanted flooding. However, natural structures are in many ways preferable to man-made structures because they are self-maintaining and are capable of adjusting in harmony with channel adjustment and evolution.

Man-Made In-Channel Structures

Channel structures and bank protection structures are examples of man-made devices that can encourage establishment of riparian ecosystems. Channel structures, ranging from large flood control and water storage structures to small check dams (gully plugs), have a similar geomorphic effect as bedrock intrusions during

cienega formation. Bank protection devices, on the other hand, do not directly obstruct channels but, by deflecting or separating streamflow, can affect nearby riparian areas (DeBano and Heede 1987).

Large Dams

Dams are one of the oldest and most common physical structures used for regulating streamflow. If the structures are designed for water storage, they will retain water until it is needed for downstream use. Flood control structures, on the other hand, only store water temporarily until it can be released safely downstream. Because of their effect on streamflow and sediment transport, large water storage and flood control dams can dramatically influence both upstream and downstream channels and associated riparian ecosystems.

Reservoirs accumulate sediment both at the dam site and in the delta where the stream enters the reservoir because flow velocities are decreased, causing suspended sediment to settle out. As a result, local base levels of the stream rise, causing aggradation in the lower stream reaches. Where bank materials are erodible, this aggradation leads to channel widening and provides excellent habitat for riparian plants. Dense plant cover (especially those consisting of brush and trees) also increases flooding of adjacent floodplains, thereby creating temporary disturbances favoring establishment of riparian ecosystems (Brady et al. 1985, Szaro 1989).

Fine sediments and organic matter deposited upstream from dams are also nutrient-rich. These deposits are not only a fertile medium for plants, but also influence moisture regimes above and below channel structures (Szaro and DeBano 1985). Deposited materials retain water for longer periods, thereby creating a more stable moisture regime for colonizing riparian ecosystems. Unfortunately, these riparian areas in the Southwest are often reoccupied by dense stands of saltcedar, which provide much poorer wildlife habitat than cottonwoods and other native species.

Case study.—A recent study of a flood control dam and reservoir in central Arizona illustrates how a large channel structure can alter streamflow and sediment regimes and enhance the establishment of a riparian ecosystem (Szaro and DeBano 1985). Whitlow Dam was built in 1960 as a flood control structure for temporarily delaying streamflow in Queen Creek by storing about 36,000 acre-feet of floodwater. The structure also stored sediment. By 1975, about 304 million cubic feet of sediment had been stored in the reservoir above the dam. Prior to construction, stream reaches above Whitlow Dam supported mainly Sonoran riparian scrubland (fig. 9a). There were no trees in the streambed, and adjoining banks supported mainly common mesquite, velvet mesquite, and ironwood. Only 7 years after completion, Gooding willow and saltcedar had occupied about 44 acres (fig. 9b). From 1967 to 1980, vegetation increased in both density and size to the 72-acre riparian community present today (figs. 9c and 10).

The rapid development and establishment of a riparian ecosystem above Whitlow Dam was in response to both

a

b

c

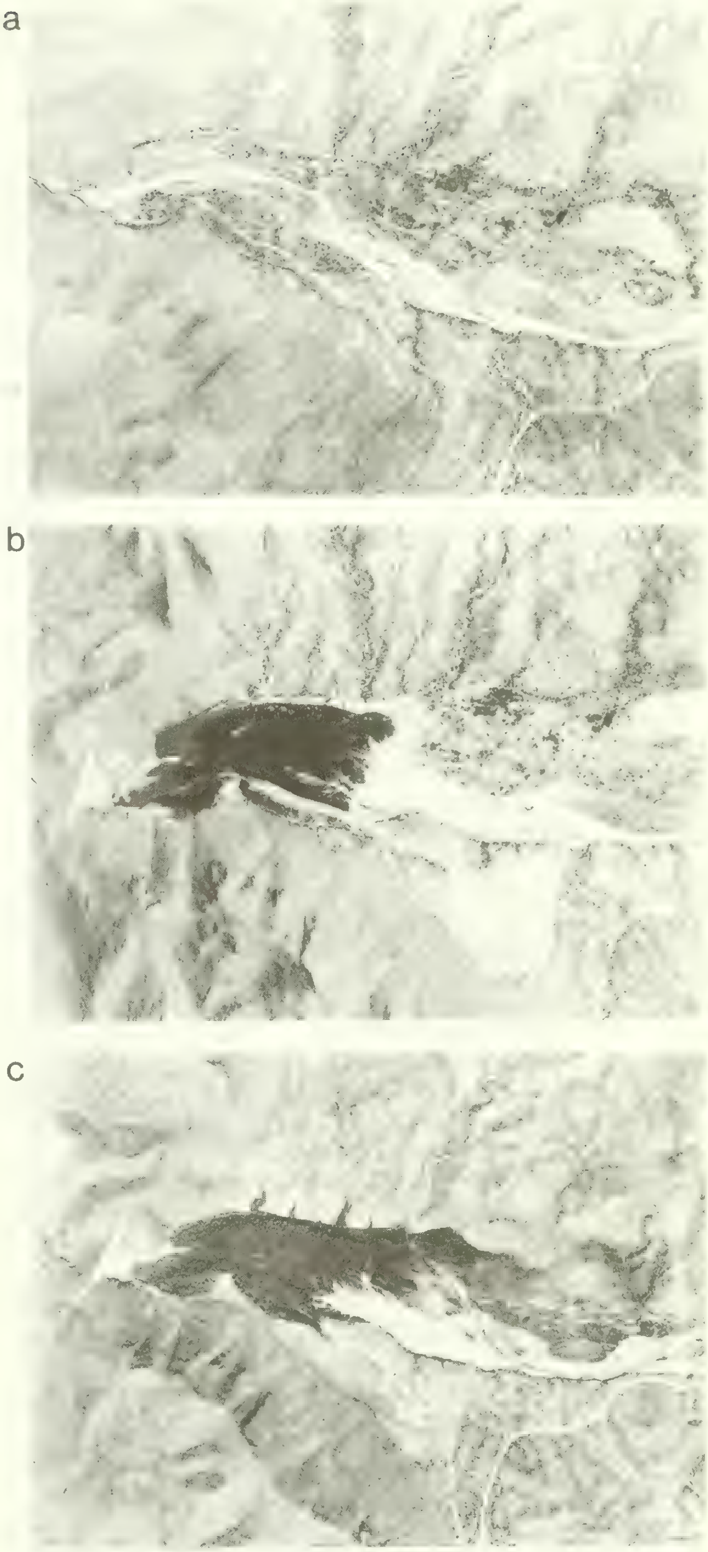

Figure 9.—Aerial photographs showing the development of a riparian plant community above Whitlow Dam in central Arizona between 1960 and 1980: (a) prior to completion of dam in 1960; (b) by June 1967, a 44-acre riparian community had developed above the dam; and (c) by April 1980, a 79-acre riparian plant community was present (Szaro and DeBano 1985).

improved moisture relations and site fertility. Temporary impoundment of water in the reservoir charges both trapped sediment and surrounding reservoir banks with water, which provides nonstorm streamflow for a large part of the year. A hydrologic analysis of the inflow records for the dam over time since its construction in 1960 showed that, had the dam not been present, the channel reach would have only been wetted during stormflows an average of 24 days per year between 1960 and 1983 (fig. 11). In contrast, outflow records indicated that after construction, streamflow occurred about 340 days annually (fig. 11).

Bank recharge may be an important mechanism for enhancing riparian areas in the Southwest. Depending on the nature of bank material, streambank recharge can occur rapidly in semiarid environments along nonperennial streams even in the absence of channel structures (Byers and Stephens 1983, Stephens 1985, Stephens and Knowlton 1986). Up to 26 acre-feet of water per mile of channel has been reported stored in coarse channel alluvium in southern Arizona (Keppel and Renard 1962). Water stored in streambanks may be released slowly over time and significantly extend the duration of streamflow (Cooper and Rorabaugh 1963). Flood control dams or other structures across ephemeral stream channels temporarily impound water, thus allowing more water to be stored in a particular stream reach as bank recharge.

Effect of large dams on downstream channel dynamics and associated riparian ecosystems.—Large dams withdraw both sediment and nutrients from streams, thereby playing an important role in downstream channel dynamics and the welfare of associated riparian areas (Brown and Johnson 1985). Sediment removal by structures produces a stream capable of picking up a fresh sediment load, because the water leaving the dam has excess available energy (DeBano and Heede 1987). Before dam installation, downstream channels are in dynamic equilibrium, supporting a flow carrying a given sediment load. After installation, this equilibrium is lost. A new equilibrium between flow and hydraulic geometry of the channel must develop. It takes time to attain this new equilibrium because stream processes are slow.

Figure 10.—A 79-acre riparian plant community above Whitlow Dam.

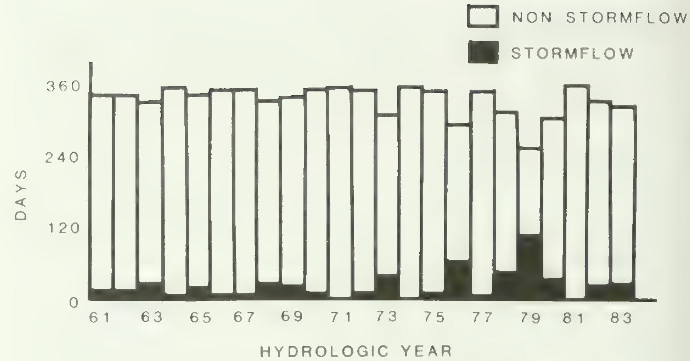

Figure 11.—The number of days per year of storm and nonstorm flow through Whitlow Dam, 1961-1983 (Szaro and DeBano 1985).

One of the most important variables influencing flow energy is channel gradient. A stream carrying less than its potential sediment load requires a gentler gradient (i.e., less free energy) or, theoretically, a rougher bedform. In reality, changes in only bedform or particle size are seldom sufficient for attaining a new equilibrium after sediment load withdrawal. Channel gradients can be decreased by meander formation, or by degradation of the bed. Where banks consist of erosion-resistant materials, or where bank protection measures are installed, lateral stream movement cannot occur. Instead, sediment load will be picked up from the bed, causing degradation and flattening of the gradient over time. Degradation is a long-term, high-energy process. Both degradation and meander formations can destroy existing riparian ecosystems.

A second major effect large dams have on downstream riparian areas is through regulation of streamflow. Although dams are built for different purposes, most decrease peak flows (Williams and Wolman 1984). Large flood control dams may delay storm flows only temporarily, while water storage structures may regulate flow throughout the year except for unexpected "spills" during large flow events that can inundate and damage nearby riparian ecosystems (Stevens and Waring 1985). When flow regulation is substantial, flooding of nearby floodplains may be eliminated. Consequently, aggradation of floodplains does not occur, which is the trigger mechanism for shifting channels. Shifting floodplain channels are required for regeneration of some riparian tree species (Brady et al. 1985, Szaro 1989). Although drastic reductions in flow may harm riparian ecosystems on floodplains removed from the stream channel, the more consistent streamflow favors riparian ecosystems in, or adjacent to, stream channels. Flow regulation may increase low flow and, thereby, be beneficial to riparian ecosystems because it provides a more reliable yearlong source of water (Williams and Wolman 1984).

Substantial decreases in flow discharge can also lead to channel aggradation. When large amounts of sediment are discharged from tributaries, the flow energies in the master stream are not sufficient to transport this material downstream (DeBano and Heede 1987). An alluvial fan then forms at the stream junction, forcing the master stream to create a new channel around the fan by eroding

the opposite bank. This can destroy portions of existing riparian ecosystems. A high frequency of tributaries with large sediment production may throw the stream and its existing riparian ecosystem out of dynamic equilibrium, and only after a new equilibrium has been attained can new riparian ecosystems become established.

The balance between sediment withdrawal and flow regulation on channel dynamics and riparian areas is illustrated by the effect of Glen Canyon Dam on the Colorado River as it flows through the Grand Canyon. The walls and channel bottoms in part of the Grand Canyon are made up of erosion-resistant material, so the most easily available material is not located in the bed but in bars within and alongside the Colorado River (Beus et al. 1985). Because sediment has been removed upstream by Lake Powell, sand on the beaches on this stretch of the Colorado River are being picked up by the relatively sediment-free water. The only depositions occurring at present are during infrequent flooding by the Little Colorado River and other smaller tributaries entering the Grand Canyon below Glenn Canyon Dam, or by unexpected "spills" through Glenn Canyon Dam (Beus et al. 1985). The remaining fluvial deposits have been transformed from barren strips on both sides of the river to dynamic strips of vegetation because large floods capable of destroying riparian areas have been reduced (Turner and Karpiscak 1980).

Synopsis.—In summary, changes in stream dynamics caused by large dams, along with overgrazing and watershed abuse, must be viewed as the prime reasons for changes in riparian ecosystems (Skinner 1986). Generally, riparian areas increase upstream and may either decrease or increase downstream. Streams carrying less than their potential sediment loads are the main reason for damage to downstream riparian areas, although regulated flow may benefit both up- and downstream riparian ecosystems.

Intermediate-Sized In-Stream Structures

Structures of intermediate size, commonly used for stabilizing channel downcutting and degradation, can stabilize stream reaches, store sediment, and enhance establishment of riparian ecosystems. The structures vary in size but are larger than the channel checks used in small gully networks. Design specifications for these types of structures, which can be used for stabilizing coarse alluvium during riparian zone rehabilitation, have been developed by Jackson and Van Haveren (1984). Although multiple structures in a channel are usually the most effective for riparian enhancement, single structures, particularly if combined with upstream cover manipulations, may serve equally well. Intermediate-sized structures have been constructed for erosion control purposes throughout the West (Lusby and Hadley 1967; Ruby 1973, 1974; Van Haveren et al. 1987).

Case study.—An intermediate-sized flood control structure that contributed to the establishment and development of a riparian community was built in Monroe Canyon on the San Dimas Experimental Forest in southern California. Monroe Canyon is a 865-acre watershed covered with chamise-chaparral and scrub-oak vegetation types (Hill and Rice 1963). Prior to treatment, about 9 acres of the canyon bottom was occupied by obligate riparian species. Another 25 acres was occupied by oak-woodland. The riparian and oak-woodland sites were harvested in 1958 and 1959 to test water yield responses, and in 1960 the entire watershed was burned by a wildfire. After the fire, brush suppression by hand labor and herbicides was used to convert sideslope sites with deep soils to an annual grass cover.

The combination of vegetation conversion, fire, and large storms during 1965, 1966, and 1969 had a tremendous impact on the channel geometry of Monroe Canyon (Orme and Bailey 1971). At the height of storms in January and February 1969, the entire canyon floor became a veritable debris chute. During the storm periods between 1963-1969, Monroe Canyon lost nearly 2,877 yd^3 of materials, over eight times the volume lost from a comparable channel reach in Volfe Canyon where erosion was hindered by vegetation, greater energy losses, and less discharge and debris production (Orme and Bailey 1970). With these powerful erosional processes operating in Monroe Canyon, the channel bottom throughout the watershed remained virtually devoid of any permanent vegetation through the late 1960's and early 1970's.

In 1972, a large flood control structure was constructed at the mouth of Monroe Canyon. This structure was a crib design, 32 feet high and 135 feet wide. The structure was rapidly filled to capacity (3,438 yd^3) with coarse debris. By 1978 a small stand of willows had become established upstream from the structure. Vegetation reestablishment was rapid, so by the spring of 1985 a substantial riparian area had become established that extended several hundred yards upstream. The present vegetation is primarily willow and Baccharis.

A riparian community also developed below the Monroe Canyon Dam due to the stabilization of a badly eroded channel and from more consistent streamflow provided by upstream brush-to-grass conversions (Hill and Rice 1963). Sediment trapped in the structure stored water, which was released slowly over time. The channel stability coupled with perennial streamflow allowed rapid reestablishment of riparian species. Similar observations were made during a comprehensive survey and analysis of thousands of similar intermediate-sized structures throughout Los Angeles County (Ruby 1973). Establishment of vegetation occurred rapidly and trees were observed occupying debris mounds above dams within 2 years (Ruby 1973).

Effect on channel dynamics.—Intermediate-sized structures function more like smaller channel checks than large dams. Substantial sediment can be withdrawn during the first storms following construction until the upstream reservoir is filled. The sediment deposits above these structures continue to aggregate until pre-dam channel gradient is attained if sufficient sediment is supplied (Van Haveren et al. 1987). Upstream deposition also depends on the permeability of the structure, with the permeable structures maintaining steeper surface gradients than the original stream channels (Lusby and

Hadley 1967). After the storage capacity of the reservoir has been satisfied, additional sediment is carried through the structure and reduces the downstream erosion potential of the stream. At this stage, their effects on downstream erosion are similar to those of small gully plugs.

Bank Protection Structures

Bank protection structures can be grouped into (1) armoring banks, (2) deflecting flows, and (3) separating flows. Armors are designed to keep banks in their present location; deflectors are used for eliminating flow impacts on critical banks; separators divide flow into high and low energy segments. The objective of the latter is to allow only low-energy flows along the banks (DeBano and Heede 1987). All three types can protect and enhance riparian plant communities if correctly designed. However, the third type, because it emulates riparian flow separation effects, yields the greatest benefit for riparian ecosystems. Indeed, enlarging a riparian plant area often is an important objective for attaining bank stability. The need for bank protection structures, as with other manmade structures, should be carefully analyzed within the context of natural adjustment mechanisms so that their success is assured. Continued maintenance and repair is also critical for the success of all types of bank protection structures.

Bank armor usually consists of various kinds of riprap, revetments, gabions, and a variety of other structures installed parallel to a bank and can be constructed according to several designs (Lafayette and Pawelek 1989; Schultze and Wilcox 1985; State of California 1970; U.S. Army 1962, 1984) (fig. 12). Design considerations must include alignment of structures relative to the bank. Smooth transitions from structure to bank on both upstream and downstream ends are necessary to prevent flow separation and eddy development which could lead to bank scour and eventually undermine and erode the riparian ecosystem. Several excellent manuals are available describing the proper installation of these types of bank protection structures (State of California 1970, U.S. Army 1962). Vegetation may also be planted on these structures to stabilize them (Schultze and Wilcox 1985).

Flow deflectors are frequently used for protecting banks and areas adjacent to the channel from the stream's impact. These deflectors can be used to save endangered riparian plant communities. However, careful engineering design is essential so deflected flows do not create new critical locations along the banks (DeBano and Heede 1987). Poor design may protect one side of the stream but cause destruction on opposite streambanks. Long-term stability of deflection structures depends on the angle between deflector and water flow lines.

Deflectors can produce eddies that scour banks and endanger the deflector. Possible solutions are to keep eddy formations at low-energy levels and to install several deflectors at relatively close intervals. Improperly designed deflectors can constrict stream channels, thereby increasing head-velocity relationships and the

a

b

c

Figure 12.—Commonly used bank armoring and protection devices: (a) revetment posts and gabion near Moab, Utah; (b) jacks and bank armor at Dodge City, Kansas; and (c) jack field behind revetment posts on the Powder River, Wyoming.

potential for erosion. The State of California (1970) and the U.S. Army (1962) have handbooks available describing their proper installation.

Flow separation structures are designed to create low-energy flows along banks. They usually consist of woven wire fences or jack/tetrahedron fields installed at some distance from the bank. One or both banks may be treated because little risk exists for deflected flows. Higher velocities occur outside the fence network (middle of the stream), while reduced flows between fence and bank lead to sediment deposition. Over time, these depositions decrease bank height which, combined with lower flow energies, increase bank stability and may encourage establishment of new riparian ecosystems.

Flow separation structures are practical for increasing bank stability and enhancing riparian plant communities only where channels are wide enough to allow deposition alongside the banks. Best suited are streambeds with high- and low-flow channels. The use of fence revetments is limited to streams having flow magnitudes that will not destroy them. Thus, large rivers may require structures such as jacks or tetrahedrons. These structures increase roughness of flow and produce the same results as fences. However, individual structures must be anchored to each other, in the channel, and to the banks in order to secure their location.

Synopsis

Both naturally occurring and man-made channel structures play an important role in riparian enhancement in select locations throughout the Southwest. As with all other expensive engineering structures, the routine construction of man-made structures is not recommended solely for enhancing riparian areas. However, the potential riparian benefits should be considered when analyzing the costs and benefits associated with structures. Managers need to be aware of, and capitalize on, the wide range opportunities for perpetuating naturally occurring structures such as log steps, large debris accumulations, snd beaver dams. Cienega formation involves larger scale long-term geologic processes, thereby limiting the manager's role mainly to that of understanding the processes responsible for their evolution and limiting any disturbances that may endanger them.

WATER USE BY RIPARIAN ECOSYSTEMS

Because water is a scare resource throughout the Southwest, it is important that managers be able to estimate amounts of water needed for the different uses, including that necessary for sustaining riparian plant communities. This section summarizes the available literature on water use by riparian plants.

Water use by a wide range of riparian ecosystems has been estimated through past research. However, it must be kept in mind that this research was done in two very different environments: (1) downstream floodplains occupied by phreatophytes, and (2) less arid upland sites occupied by forest or chaparral vegetation. It is important to distinguish between these two environments when assessing the costs and benefits associated with water use by riparian ecosystems in the Southwest. Although water consumption by riparian species is high in both situations, water use by phreatophytes in desert and semidesert environments is notoriously high. Consequently, past watershed research was concerned mainly with methods of controlling phreatophytes to reduce evapotranspiration and conserve water along large river systems (Bowie and Kam 1968, Campbell 1970, Graf 1980, Horton and Campbell 1974). Some research on water augmentation was also done in upland riparian areas (Baker 1984, 1986; Ffoliott and Throud 1974; Hibbert et al. 1974; Rich and Gottfried 1976; Rowe 1963).

Riparian vegetation in Arizona occupies about 276,000 acres, of which more than 100,000 acres are located at lower elevations along the Gila River (Babcock 1968). The acreage of riparian vegetation occupying upland sites is not precisely known, although the U.S. Forest Service (Southwestern Region) estimates it administers about 240,000 acres of riparian areas in Arizona and New Mexico, most of which are probably classified as upland sites (personal communication, Russell Lafayette, Southwestern Region, USFS).

Lower Elevation Riparian Ecosystems

Lower elevation stream banks are occupied by several riparian species including Gooding willow, Fremont cottonwood, and saltcedar. Saltcedar was introduced into the United States by nurserymen during the early 1800's (Horton 1964) and spread rapidly; it occupied about 890,000 acres of floodplain by 1961 (Horton 1977). Large amounts of water used by phreatophytes, such as saltcedar, have made them attractive species to remove for water augmentation purposes. Sites supporting saltcedar and other riparian species consume 8 to 70 inches of water annually through evapotranspiration (Anderson 1976, Gay 1985, Gay and Hartman 1982, Schumann and Thomsen 1972, Thomsen and Schumann 1968).

Lower elevation riparian ecosystems consume substantial amounts of any additional water gained from treating upstream areas during its conveyance. The fate of this additional water in terms of present, near-future, long-term, and potential evapotranspiration was estimated on 32 intermittent and perennial stream reaches in Arizona (Anderson 1976). Near-future and long-term increases in evapotranspiration were considered negligible for perennial streams, which accounted for about one-half of the streams and two-thirds of the total stream length. Near-future evapotranspiration increased in intermittent stream reaches because shallower water tables were produced when additional water was made available. Long-term future evapotranspiration also increased because riparian vegetation density increased as water became permanently available in areas that were previously intermittent. Estimates of evapotranspiration varied from one reach to another, but usually long-term future consumption is projected at more than double present consumptive use.

The results of a study on conveyance losses were used to estimate potential water use in Tonto Creek above Lake Roosevelt in central Arizona. Tonto Creek is 59 miles long and supports 4,850 acres of riparian vegetation. Estimates of present, near-future, and long-term future evapotranspiration, in millions of cubic feet per year, were 378, 523, and 78, respectively. Thus, it was anticipated that if water yield was increased in Tonto Creek by vegetation from cover manipulations, the first 403 million cubic feet of this increased water could be used along the stream by riparian vegetation unless remedial control were applied to the vegetation. One should not assume from these projections, however, that the first 403 million cubic feet of any annual water yield increase, or even the first 145 million cubic feet (Anderson's near-future losses), would be consumed enroute to Lake Roosevelt. Evapotranspiration occurs largely in the summer, not during the dormant winter season when about 80% of the increase in water yield, resulting from cover manipulations, is produced (Hibbert et al. 1974). Since most of these intermittent streams flow in winter (except for very dry years), any increase in flow, however small, would simply add to the existing flow and little or no additional use should occur enroute to downstream storage. In contrast, increases in summer flow would not fare as well, because when normal streamflow is consumed by riparian vegetation, any extra flow would likely also be consumed. If water yield is increased to create perennial flow in formerly intermittent streams, then further depletion of summer flows will eventually reach a maximum rate (Anderson's long-term future losses), after which use would remain constant. However, in the interim, transitory use of water should be no greater than 2% of the water yield increases unless the stream normally does not flow at least part of each year. In this event, increases might be completely absorbed into dry channels and bank alluvium.

Upland Riparian Zone Water Use

Evapotranspiration from upland riparian zones varies widely, depending on elevation, presence and depth of water in alluvium, and type and density of vegetation. Three studies, two in Arizona and one in southern California, provide estimates of evapotranspiration rates from upland riparian areas.

Rich and Gottfried (1976) found that removal of bigtooth maple, Arizona alder, and Arizona walnut from a narrow riparian zone along the north fork of Workman Creek at 4,300 to 7,000 feet elevation in central Arizona, caused no detectable changes in daily fluctuations or annual or growing season streamflow. Bowie and Kam (1968) studied water use along a 1.5-mile stream reach on Cottonwood Wash in northwestern Arizona at an elevation of 4,000 to 4,300 feet. Treatments were applied to defoliate and eradicate riparian vegetation, mostly cottonwoods and willows, along a 22-acre floodplain about 121 feet wide. Defoliation produced only small and short-lived reductions in water use by riparian vegetation. Eradication, on the other hand, reduced water consumption on the 22 acres from 32 million cubic feet (3.6 feet deep) to 18 million cubic feet (2.0 feet) per growing season for 3 years.

Rowe (1963) reported water was saved when woodland-riparian vegetation was cut along 1.3 miles of Monroe Canyon in the San Gabriel Mountains of southern California. Evapotranspiration in Monroe Canyon was estimated to be between 4 and 5 feet annually in areas at elevations from 2,000 to 2,500 feet. Only about 10% of the area cleared (34 acres) supported riparian plant communities. When the increases in water were prorated over the acreage treated, flow increased more than 1.2 acre feet annually per acre treated.

Synopsis

When evaluating actual or potential water use by riparian vegetation, a clear distinction must be made between small stringers of riparian vegetation along upland streams and extensive riparian ecosystems occupying the lower elevation rivers and floodplains in desert environments. Important differences include season and duration of water flow and use, aridity of environment, and size of individual riparian ecosystems.

In upland environments, the most effective precipitation and streamflow occurs during winter, when riparian plants are dormant and using little water. Therefore, during winter only a small portion of the available water is used by riparian ecosystems located at the higher elevations. During summer, however, these upland riparian communities are using a maximum of water, although the amount used per unit area is probably less than the riparian ecosystems in the more arid desert environment where the evapotranspiration potential is notoriously high. Currently, there are no definitive inventories of the total riparian areas in each environment, although individual ecosystems are much larger along the rivers in the lower elevation deserts (e.g., Gila River in Arizona). However, there are some indications that, by innovatively managing the depth to the water table below floodplains supporting phreatophytes in these desert environments, water may be conserved by reducing evapotranspiration without jeopardizing the integrity of the riparian ecosystem (Ritzi et al. 1985).

RESEARCH NEEDS

Although land managers are implementing numerous watershed practices that improve riparian area hydrology, our present understanding of the effect of specific watershed treatments on the dominant hydrologic processes operating in these riparian areas is incomplete. Research is needed to better clarify: (1) specific sequences of treatments needed for establishing an acceptable balance between watershed condition and riparian health as related to different management objectives; (2) the role of sideslope vegetation on channel processes, such as peak flow generation and sediment transport (Gregory et al. 1985); (3) the role of riparian communities

on nutrient dynamics, sediment transport, and contaminant capture in associated streams (e.g., "nutrient sinks," denitrification in moist stream environments, etc.); (4) the dynamic exchange of water between surface and ground water sources and its effect on associated riparian ecosystems (e.g., streambank and alluvial fan recharge, ground water recharge, etc.); (5) long-term success, proper location, and role of channel structures in riparian enhancement (Platts and Rinne 1985); and (6) evolution of incised channel systems and the long-term role of channel structures in riparian rehabilitation.

Much has been written about the effect of plant cover and general watershed condition on infiltration, runoff, and erosion. Good watershed condition is generally accepted as a prerequisite for maintaining a healthy riparian community. However, the reversibility of degraded watershed condition is poorly defined. Likewise, the dynamic balance between watershed and channel parameters during rehabilitation of badly deteriorated watersheds is not well understood, particularly at any specific point in time. A better quantification of the balance between watershed condition and riparian health is needed for effective management of existing, or potential, riparian ecosystems throughout the Southwest.

Riparian areas act as active sinks for nutrients, organic matter, and contaminants (Lowrance et al. 1984a, 1984b, 1984c). Streamside vegetation traps both sediment and chemicals generated on agricultural uplands before they are transported to nearby stream channels (Hayes et al. 1979; Lowrance et al. 1985, 1986; Peterjohn and Correll 1984; Peverly 1982; Schlusser and Karr 1981a, 1981b). If these nutrient sinks, or buffer strips, are also active in upland riparian areas, they may play a key role in controlling downstream movement of nutrients, sediment, and contaminants released during different watershed treatments. This filtering effect could be an important consideration when managing downstream nitrate contamination produced by converting chaparral to grass (Davis 1985, Riggan et al. 1985). In Arizona, nitrate concentrations of stream water were found to increase from less than 1 part per million, prior to brush control, to as high as 60 to 69 parts per million the third and fourth year following brush control (Davis 1985). The effect of riparian stringers on nitrate concentrations in upland stream environments in Arizona has not been quantified, although riparian forest and wetland ecosystems in the headwater watersheds of Lake Tahoe were found capable of removing 99% of the incoming nitrate nitrogen (Rhodes et al. 1985). If this level of removal was possible during operational scale brush-to-grass conversions in Arizona, then riparian stringers produced, as a result of these conversions, could play an important role in reducing nitrate levels in streamflow before it reached downstream domestic uses.

Although the overall, but not unqualified, beneficial effect of channel structures on hydrologic regimes in riparian areas has been well documented by numerous case studies, criteria have not been developed to identify the incised channels needing treatment and those which will heal naturally. Little is known about the amounts and rates of water recharge, storage, and release from sediment accumulations and adjoining banks in impoundment areas upstream from structures. Rate and amount of bank and sediment recharge and water storage along with the subsequent release of this water slowly over time needs to be better quantified so the effect of channel structure size on potential riparian areas can be more precisely identified during land management planning.

SUMMARY AND CONCLUSIONS

Management of riparian areas is a critical issue in the southwestern United States. Riparian areas are recognized as unique and valuable habitats whose welfare strongly depends on the health of the surrounding watershed. These riparian areas are found in two distinctly different environments—along small streams in higher elevation uplands, and the large downstream rivers which pass through hot desert environments. Large-scale perturbations (overgrazing, timber harvesting, poor road construction, fuelwood cutting, etc.) of watersheds and associated riparian areas in the 19th century, coupled with emphasis on water yield augmentation in the mid-20th century, led to the degradation of many naturally occurring riparian areas throughout the Southwest.

Land managers are currently implementing a variety of watershed treatments that can improve the structural attributes of riparian ecosystems. In some cases, these treatments may not have been designed for improving riparian areas. However, they have created a more stable environment and favorable hydrologic regime which, in turn, has allowed riparian ecosystems to become established. The most obvious practices benefiting riparian areas are upstream treatments aimed at improving watershed condition, increasing duration of streamflow while moderating flood peaks, and stabilizing channels to reduce erosion.

Improving watershed condition involves improved land use management, which is sometimes supplemented by cultural treatments, to increase plant cover and vigor. Mechanical stabilization of channels may become a necessary part of restoration treatment when significant gullying has occurred. Additional water can be obtained for upland ecosystems by reducing evapotranspiration losses through plant cover manipulations and harvesting.

Man-made and naturally occurring channel structures play an important role in riparian management strategies in the Southwest. Large dams for flood control or water storage can both stabilize erodible channels and extend streamflow duration by trapping sediment in upstream deposits, which then store and release water slowly over time. Perennial streamflow may result. Deposited sediments also provide a nutrient-rich substrate favoring plant establishment and growth. Networks of small- and intermediate-sized dams can produce an effect similar to that obtained from large structures. Several naturally occurring processes, operating at different scales, provide the basis for floodplain and associated

riparian development. These include changes in channel slope resulting from landslides, alluvial fans, log-step formation, beaver dam construction, and larger scale geologic changes, such as cienega formation. Managing these naturally occurring and man-made riparian ecosystems requires understanding the hydrologic and hydraulic processes responsible for their formation.

Channel structures for rehabilitating riparian areas cannot be installed without some risk. Channel aggradation induced by structures may be of such magnitude that existing riparian zones are buried. On the other hand, if the structure is large enough to remove most of the sediment load, it may cause erosion in downstream riparian areas because the sediment-free water has sufficient free energy to pick up and transport sediment. Also, if a dense riparian community obstructs the spillway of a small dam, it may divert flood flows around the structure and erode formerly stable areas.

Establishing and maintaining riparian areas require tradeoffs among various uses, including recreation, wildlife and fisheries habitat, grazing, and water yield augmentation. On upland areas, the use of available water by riparian stringers is probably minimal because most water production and streamflow occur mainly during the winter when evapotranspiration is lowest. Establishment and maintenance of these riparian zones appear to depend heavily on the timing of streamflow rather than total increases in water production. This is the reason temporary storage devices such as channel structures are effective for promoting riparian establishment. At lower elevations, evapotranspiration losses are high and the cost of sustaining riparian ecosystems is more expensive in terms of water consumption.

Although many fundamental hydrologic principles are applicable to riparian zone hydrology, the site-specific role of different watershed treatments in successful rehabilitation of deteriorated watersheds has not been well defined. An understanding of the dynamic balance between watershed condition and riparian health for specific sites is also necessary for managing existing or identifying potential riparian areas. Additional research is needed on channel evolution and the role of channel structures in rehabilitation of incised channel systems and riparian areas. Engineered structures that best emulate the natural attributes of riparian areas are not well known. The relationships between nutrient cycling, bank recharge, and streamflow resulting from installation of different sizes of channel structures are other important areas for future research.

In summary, healthy riparian areas reflect sound watershed conditions. Riparian areas provide the final natural treatment of watershed flows to filter sediments, remove nutrients, control water temperatures, and regulate base and flood flows. These areas must be considered in a watershed context, because all tributary effects accumulate to influence riparian health and stability. Upland watersheds in good condition absorb storm energies, regulate storm flows through the soil mantle, and, as a result, provide stability to the entire watershed. This, in turn, provides sustained flows necessary for supporting healthy riparian ecosystems. In contrast, abused watersheds have developed expanded channel networks in response to increased surface flows. These networks maintain undesirable flashy runoff and available sediment. Watershed and channel treatments are often required in conjunction with improved land use management to rehabilitate these problems.

Successful treatment programs require a clear picture of the desired balance between riparian health and watershed condition; an understanding of departures from this desired balance enables managers to select the best combination of management and treatments needed to improve riparian health. The basic knowledge for improving watershed and riparian areas is generally available. However, the key to successful rehabilitation lies not only in the wise and timely application of management principles and technology, but also requires establishing predictable and quantifiable treatment goals.

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APPENDIX A
Discussion of Riparian Terminology

Riparian areas may be defined in a variety of ways, based on factors such as vegetation type, groundwater and surface water hydrology, topography, and ecosystem function (Swanson et al. 1982). These factors have so many complex interactions that defining the riparian area in one sense integrates elements of several other factors. Riparian areas are viewed as important islands of diversity within extensive forest and rangeland ecosystems throughout the West, and often support complex mosaics of plant communities associated with a unique combination of soil and hydrologic characteristics (Platts et al. 1987).

Riparian areas are generally characterized by environmental processes markedly different from those prevailing on upland sites. For this reason, many western forest and rangeland classification concepts are not useful for describing riparian areas. Riparian areas are geomorphically active, with periodic natural disturbances affecting soil and hydrologic characteristics. Water tables may be subject to fluctuations at relatively frequent intervals (Platts et al. 1987). However, riparian vegetation community types represent more than current floristic units. These types can be fairly well correlated with soil and environmental characteristics so reliable inferences can be drawn regarding environmental gradients and successional relations between types. Therefore, riparian vegetation communities cannot be termed "habitat types." The latter term refers to areas of land capable of supporting long-term stable (climax) communities, a situation seldom realized in riparian areas.

Webster defines riparian as "of relating to, or living on the bank of a river, lake, etc." and is derived from the Latin *riparius* meaning bank or shore, as of a stream or river. This original meaning has been largely retained, and is used to describe terrestrial, moist soil zones immediately landward of aquatic wetlands, other freshwater bodies, both perennial and intermittent watercourses, and many estuaries. Numerous other specific definitions have also been proposed. For example, The Society for Range Management (Anderson 1987) defines "riparian zones, or areas, are the banks and adjacent areas of water bodies, water courses, seeps, and springs whose water provide soil moisture sufficiently in excess of that otherwise available locally so as to provide a more moist habitat than that of contiguous flood plains and uplands." The Bureau of Land Management (Anderson 1987) states "riparian areas are zones of transition from aquatic terrestrial ecosystems, whose presence is dependent upon surface and/or subsurface water, and which the influence of water reveals through their existing or potential soil-vegetation complex. Riparian areas may be associated with features, such as lakes, reservoirs, estuaries, potholes, springs, bogs, wet meadows, muskegs, and ephemeral, intermittent or perennial streams." A definition suggested by Anderson (1987) is "a riparian area is a distinct ecological site, or combination of sites, in which soil moisture is sufficiently in excess of that otherwise available locally, due to run-on and/or subsurface seepage, so as to result in an existing or potential soil-vegetation complex that depicts the influence of that extra soil moisture." Riparian areas may be associated with lakes, reservoirs, estuaries, potholes, springs, bogs, wet meadows, muskegs, and intermittent or perennial streams. The distinctive soil-vegetation complex is often the differentiating criterion.

Ecologists in the eastern United States tend to be more restrictive than those in the arid West when using the term "riparian" (Johnson and Carothers 1982, Lowe et al. 1986). Many eastern biologists would restrict the definition of riparian areas to the habitats closely paralleling bottomlands, floodplains, or first terraces along flowing streams. In the eastern environment, riparian plant communities may not differ greatly from upland plant communities (Johnson and Lowe 1985). Investigators in arid sections of the West commonly extend the use of the term to include banks of arroyos that may flow only a few days each year, at best, and even to desert oases.

Most water sources, whether surface or ground water near the surface, in desert areas will have associated distinctive riparian vegetative assemblages. In an arid or semiarid environment, the riparian plant communities form linear woodlands that are framed sharply by contrasting deserts, scrublands, and forests of the surrounding uplands. Because water is an overriding factor in western riparian ecology, it has been proposed that streams be divided into three basic types of flow regimes: (a) perennial—associated with permanent water; (b) intermittent—areas where water is available for only a few months of the year, often during one or two seasons; and (c) ephemeral—found along watercourses which flow irregularly for short periods (less than 1 month) after local precipitation (Johnson et al. 1984). Most of the discussions in this paper concerned with the enhancement of riparian areas using watershed practices in the Southwest will be focused on upland areas and, to some extent, the lower elevation desert environments. Many of these areas would be classified as intermittent and ephemeral before treatment, and perennial following rehabilitation or enhancement.

APPENDIX B

Plant species follow Kearney and Peebles (1951) and Vines (1960).

Trees, Shrubs, and Grasslike Plants

Scientific Name and Authority	Common Name
Acer grandidentatum Nutt.	bigtooth maple
Alnus oblongifolia Torr.	Arizona alder
Baccharis sp.	Baccharis
Baccharis sarothroides Gray	broom baccharis
Carex sp.	sedge
Cercocarpus betuloides Nutt.	birchleaf mountainmahogany
Juglans major (Torr.) Heller	Arizona walnut
Quercus emoryi Torr.	Emory oak
Quercus gambelii Nutt.	Gambel oak
Quercus turbinella Greene	shrub live oak
Olneya tesota Gray.	ironwood
Populus sp.	cottonwood
Populus fremontii Wats.	Fremont cottonwood
Prosopis juliflora	common mesquite
Prosopis velutina (Woot.)	velvet mesquite
Rhus ovata Wats.	sugar sumac
Salix sp.	willow
Salix goodingii Ball.	Gooding willow
Salix laevigata Bebb.	red willow
Tamarix pentandra Pall.	saltcedar

ACKNOWLEDGMENTS

The authors acknowledge Dr. Burchard H. Heede, Research Hydrologist, USFS, Tempe, Arizona, for providing photographs of channel structures at Alkali Creek, Colorado, and Mr. William R. Hansen, National Park Service, Fort Collins, Colorado for suggestions and initial drawings for figures 4 and 5 and figures 3a and 3b.

The authors would also like to acknowledge the following reviewers who provided indepth technical comments on the manuscript during various stages of review: Dr. Malchus Baker, Research Hydrologist; Dr. Burchard H. Heede, Hydrologist; Dr. John Rinne, Research Fisheries Scientist; Dr. Robert Szaro, Research Wildlife Scientist (currently with USFS, FER, Washington, DC), USFS, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona; Dr. John H. Brock, Associate Professor, Arizona State University, Tempe; Mr. Tom Collins, Hydrologist, USFS, Intermountain, Ogden Utah; Mr. Robert D. Doty, Air Resources Management, USFS, Pacific Southwest Region, San Francisco, California; Dr. Lee Edleman, Department of Rangeland Resources, Oregon State University, Corvallis; Mr. William R. Hansen, Hydrologist, USFS, Gila National Forest, Silver City, New Mexico (currently with U.S. Park Service, Fort Collins, Colorado; Ms. Winifred Hodge, Hydrologist, Engineering Division, Department of the Army, Corps of Engineers, Champaign, Illinois; Dr. William Jackson and Dr. Bruce Van Haveren, Hydrologists, USDI Bureau of Land Management, Denver, Colorado (Dr. Jackson is currently with U.S. Park Service, Fort Collins, Colorado); Mr. Martin Jakel, Wildlife Biologist, USDI Bureau of Reclamation, Phoenix, Arizona; Mr. William Kenworthy, Hydrologist, Coconino National Forest, Flagstaff, Arizona; Mr. Russell A. Lafayette, Hydrologist, USFS, Southwestern Region, Albuquerque, New Mexico; Dr. Lyndon Lee, Senior Wetland Ecologist, U.S. EPA, Washington, DC; Ms. Donna Linquist, Hydrologist, Pacific Gas and Electric Company, San Ramon, California; and Dr. Sherman Swanson, Range Scientist, University of Neveda, Reno.

DeBano, Leonard F.; Schmidt, Larry J. 1989. Improving southwestern riparian areas through watershed management. Gen. Tech. Rep. RM–182. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 33 p.

This paper reviews opportunities and watershed restoration techniques available for rehabilitating and enhancing riparian ecosystems in southwest environments. As such, it is intended to serve as a state-of-the-art report on riparian hydrology and improvement in both naturally occurring and man-made riparian areas throughout the Southwest.

Keywords: Watershed management, riparian enhancement, watershed rehabilitation

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Mountains

Southwest

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Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-183**

Surface Mine Impoundments as Wildlife and Fish Habitat

Mark A. Rumble

Abstract

Past methods of surface mining in the northern High Plains to extract coal, sand, gravel, bentonite, and uranium left a series of blocked drainages and depressions, which later filled with water. These surface mine impoundments, created prior to passage of reclamation laws, provide poor fish and wildlife habitat. These unreclaimed surface mine impoundments, and impoundments created in the future could provide valuable fish and wildlife habitat if recommendations given here pertaining to water quality, impoundment morphometry, and vegetation communities are incorporated into mine plans.

USDA Forest Service
General Technical Report RM-183

December 1989

Surface Mine Impoundments as Wildlife and Fish Habitat

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Surface Mine Impoundments as Wildlife and Fish Habitat

Mark A. Rumble

Introduction

Prior to the enactment of State and Federal laws regulating mining activities, it was common practice to remove and lay aside the overburden, remove the minerals, and then move on to the next site. This practice left a series of barren overburden spoils and mined-out depressions that later filled with water, creating barren surface mine impoundments.

The Surface Mining Control and Reclamation Act of 1977 (P.L. 95–97) prohibited this type of abandonment. Because mining companies are now required to reclaim mined lands to equal the original productivity of the land, very few new surface mine impoundments have been created. However, a well-designed impoundment should be an alternative for reclaiming final cut areas (the last area mined in a surface mine) and areas where mining has destroyed existing wetlands (Parr and Scott 1983).

Approximately 57% of the subbituminous and 97% of the lignite coal reserves of the United States are in the northern High Plains (eastern Montana and Wyoming, western North Dakota and South Dakota, and northwestern Nebraska) (Averitt 1973). This semiarid region also contains significant reserves of other minerals, including sand and gravel, bentonite, and uranium. Surface mining is the primary method of extracting these minerals in the northern High Plains. Creation of carefully designed surface mine impoundments or the reclamation of existing impoundments represent opportunities for improving the quantity and quality of wildlife and fish habitats.

Fish and wildlife habitat studies conducted on livestock watering impoundments in the northern High Plains provide information that can be extrapolated to surface mine impoundments. Most livestock watering impoundments in this region were created by constructing earthen dams across drainages. This paper reviews studies that describe habitat parameters desirable to some targeted fish or wildlife species in the northern High Plains.

Existing Mine Impoundments

Water Quality

McWhorter et al. (1975) demonstrated that the chemical properties of the water in surface mine impoundments are similar to those of the spoil banks surrounding the impoundment. As a result of past mining practices where the deepest earthen material removed was on the top of the spoils, some surface mine impoundments contain water of poor quality. Still, most surface mine impoundments in the northern High Plains contain water suitable for use as drinking water for wildlife and livestock (Goering and Dollhopf 1982, Rumble 1985). However, sulfates, total dissolved solids, and lead concentrations in some surface mine impoundments exceeded the recommended standards for wildlife or livestock drinking water (Rumble 1985). Since other anions are also present in the water, testing for total dissolved solids and evaluating the results against the recommended maximum level of 7,000 ppm can serve as a useful indicator of water quality.

The problem of oxidation of spoil materials and resulting acid run off on eastern coal mine spoils (Crawford 1942, Davis 1971, Dinsmore 1958, Riley 1960, Simpson 1961, Struthers 1964) generally does not occur in the northern High Plains (Olson 1981). Instead, sodium and magnesium sulfates predominate in spoil materials and surface mine impoundment water (Sandoval et al. 1973, Ringen et al. 1979). Existing surface mine impoundments in the northern High Plains, which had pHs in the range of 7.0–9.0 (Anderson et al. 1979), were within recommended limits (McNeely et al. 1979).

Physical Characteristics

Several authors have studied the morphometry and vegetative characteristics of existing surface mine impoundments in the northern Great Plains (Anderson et al. 1979, Bjugstad et al. 1983, Fulton et al. 1983, Rumble et al. 1985). Such impoundments in this region meet few habitat requirements of fish and wildlife (Hawkes 1978). Surface mine impoundments created before reclamation laws were in effect generally have steep slopes below and above water level (Bjugstad et al. 1983, Rumble et al. 1985). Thus, erosion of spoil bank materials and turbidity of water can be extensive (fig. 1). Prelaw surface mine impoundments are also relatively small in surface area and in some cases quite deep; therefore, they have restricted littoral zones with little or no drawdown areas (Rumble et al. 1985). Because aquatic plant community productivity and development are enhanced by littoral zones (fig. 2) and areas of drawdown (Kadlec 1962), unreclaimed surface mine impoundments are not as productive as livestock watering ponds which have more gentle slopes, greater drawdown areas, and more diverse aquatic plant communities (Bjugstad et al. 1983).

The physical nature of the shoreline may restrict the use of surface mine impoundments by livestock and some wildlife species. It is not uncommon for animals, especially sheep, to become stuck in mud or not be able to get up the steep banks of some existing bentonite surface mine impoundments.

Recommendations: How to Make Better Habitat for Wildlife and Fish

Waterfowl

Past research has described the habitat features of livestock watering impoundments in the northern High Plains selected by waterfowl (Evans and Kerbs 1977, Lokemoen 1973, Roberson 1977, Mack and Flake 1980, Rumble and Flake 1983). These may be extrapolated to surface mining impoundments. Waterfowl production on surface mine impoundments will depend on how well three habitat requirements are met (fig. 3): (1) feeding areas for breeding adults; (2) nesting cover; and (3) brood rearing areas (Lokemoen et al. 1984a).

Surface mine impoundments to be managed for waterfowl should have surface areas between 0.4 and 4.0 ha (Proctor et al. 1983, Uresk and Severson 1988). Breeding waterfowl pairs, as well as hens with broods, appear to prefer ponds with greater shoreline length (Mack and Flake 1980, Roberson 1977). Shoreline length is related both to the size of an impoundment and irregularity of the shoreline created by peninsulas and inlets. Uresk and Severson (1988) recommended that the minimum shoreline development (shoreline length divided by circumference of a circle with equal area) index on ponds for waterfowl should be 2.2. Impoundments with 0.4 ha and 4.0 ha of surface area should be designed with at least 493 m and 1559 m of shoreline, respectively.

Impoundments or ponds with several temporary, semipermanent, and permanent wetlands in the immediate vicinity have greater use by waterfowl. Lokemoen et al. (1984a) suggested that the best waterfowl habitats contained about 12–40 wetlands of various sizes and shapes per km^2. Although this density may not be achievable in many areas, it is an indication that "more is better." Higher densities of wetlands also resulted in higher use by waterfowl broods of livestock watering impoundments, probably because the area attracted more breeding pairs (Rumble and Flake 1983).

Shallow, temporary wetlands provide a source of aquatic invertebrates sought by adult ducks in the spring (Krapu 1974, Swanson et al. 1974). These invertebrates are important to the breeding physiology of dabbling ducks (Krapu and Swanson 1975). Abundance and dispersion of aquatic invertebrates has been demonstrated to influence the numbers and habitat selection patterns of waterfowl (Kaminski and Prince 1981, Murkin and Kadlec 1986).

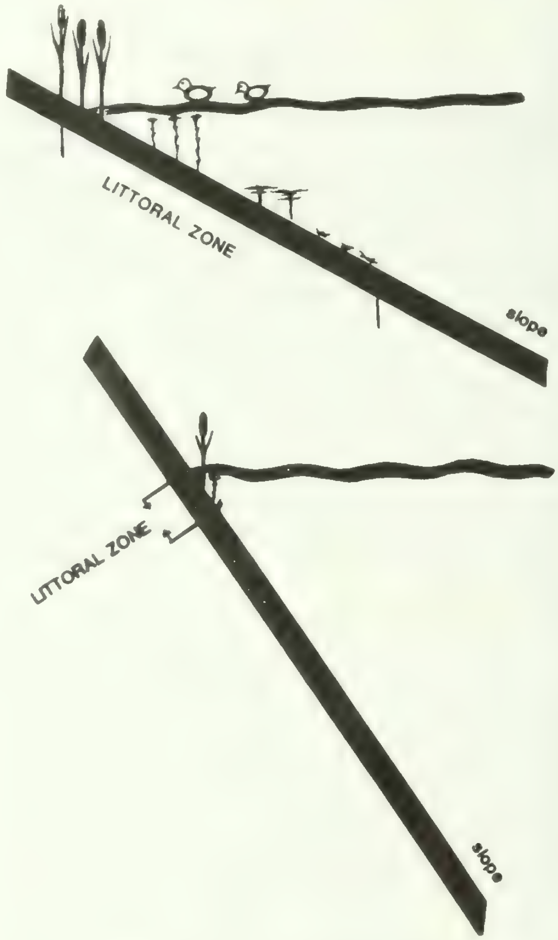

Figure 2.—More gentle slopes mean greater areas of the pond bottom receive enough sunlight to support diverse aquatic plant communities.

Figure 1.—Steep slopes lead to high erosion, high turbidity, little emergent vegetation, and poor wildlife and fish habitat.

Figure 3.—Good waterfowl habitat includes feeding areas, nesting cover, brood rearing areas.

Waterfowl use of impoundments is greater where diverse aquatic vegetation communities are interspersed with open water (Beard 1953, Kaminski and Prince 1984). Brood-rearing ponds should contain habitats typical of a "deep marsh" (Stewart and Kantrud 1971) until at least mid-August (Lokemoen et al. 1984a). Mallard broods appeared to prefer impoundments with emergent stands of roundstem bulrush (*Scirpus*), spikerush (*Eleocharis*), and smartweed (*Polygonum*) (Rumble and Flake 1983).

Management of impoundments for waterfowl should be directed at maintaining 1500 stems/m^2 of aquatic vegetation in shallow areas (Uresk and Severson 1988). Submersed vegetation provides habitat for aquatic invertebrates (Moyle 1961) and livestock watering impoundments with extensive stands of submersed vegetation had greater use by waterfowl broods (Rumble and Flake 1983). Since use of man-made impoundments by duck broods was greater on ponds with higher densities of benthic invertebrates, impoundments should be managed to maintain at least 150 benthic organisims/m^2 (Belanger and Couture 1988).

Aquatic plant communities can be managed by managing the depth of the water. Emergent species of vegetation, except "hybrid" cattail, were killed at water depths greater than 60 cm (Harris and Marshall 1963), and 76 cm of water appeared to thin out "hybrid" cattail stands (Lind et al. 1976). If dabbling ducks are the management objective, impoundments should be between 0.3 and 2.0 m deep, and less than 60 cm deep over 30–70% of the pond area; for diving ducks the depth should be between 0.6 and 2.4 m and average 1.0 m (Lokemoen et al. 1984a, Monda and Ratti 1988, Proctor et al. 1983, Uresk and Severson 1988).

The abundance of nesting cover is related to waterfowl use of ponds (McEnroe 1976); intensive grazing of pastures surrounding ponds resulted in decreased waterfowl breeding pairs (Roberson 1977). Ducks and geese readily nest on islands, sometimes in very high densities, if they are secure from predators (Lokemoen et al. 1984b). Creating islands in surface mine impoundments will therefore improve the quality of the nesting habitat for ducks and geese (Proctor et al. 1983). Islands in impoundments less than 20 ha in size should be 6–12 m across (Guthery and Stormer 1984). Dense grass or brushy shorelines are also preferred by waterfowl broods (Gjersing 1975, Rumble and Flake 1983).

Livestock management practices such as deferred or rest rotation grazing systems, distributing salt in pastures, and maintaining proper use on adjacent grazing lands will help meet some of the habitat requirements of waterfowl. Fencing portions of lands adjacent to impoundments where livestock concentrate for drinking water may be necessary in some situations so that shoreline and emergent vegetation are maintained.

Other Avian Species

Surface mine impoundments that can be modified or created to provide waterfowl habitat should also attract shore birds and some upland bird species (Evans and Kerbs 1977, Hawkes 1978, Schaid 1979, Uresk and Severson 1988) (fig. 4). Sharp-tailed grouse, prairie chickens, sage grouse, and pheasants all require water under the semiarid climate of the northern High Plains. These birds will also use vegetation surrounding impoundments for protective cover. By reducing slopes and creating irregular shorelines with inlets and peninsulas (Olson and Barker 1979) and then maintaining adequate shoreline vegetation, most surface mine impoundments can become valuable wildlife habitat. If aquatic or shoreline vegetation does not become established readily, transplants can be used to start development of vegetation communities (Fulton et al. 1983).

Figure 4.—Good habitat for waterfowl is also good habitat for other nongame avian species.

Fish

Surface mine impoundments in the northern High Plains can also provide habitat for fishes. One of the most important requirements for impoundments to be stocked with fish is a permanent supply of water of adequate quality (Proctor et al. 1983). For the most part, the water quality in surface mine impoundments is acceptable for fish (Anderson et al. 1979). Some surface mine impoundments have been stocked with walleye (*Stizostedion canadense*), largemouth bass (*Micropterus salmoides*), catfish (*Ictalurus* spp.), and rainbow trout (*Salmo gairdneri*).

Impoundments greater than 0.8 ha require less management input (SCS 1971), and ponds less than 0.4 ha surface area probably will not sustain fish for long without management (Marriage and Davison 1971). Littoral zones, areas with water less than 1 m deep, are productive areas of food for some fishes. Although vegetation in the littoral zone provides food cover for young fish, vegetation of fish ponds should occupy less than 25% of the pond area (Scalet and Modde 1984). At least 25% of the pond area should be greater than 3.0 m deep if a fishery is a reclamation goal (Scalet and Modde 1984, U.S. Department of Agriculture 1971).

Turbidity in ponds reduces light penetration through the water which reduces the potential productivity of

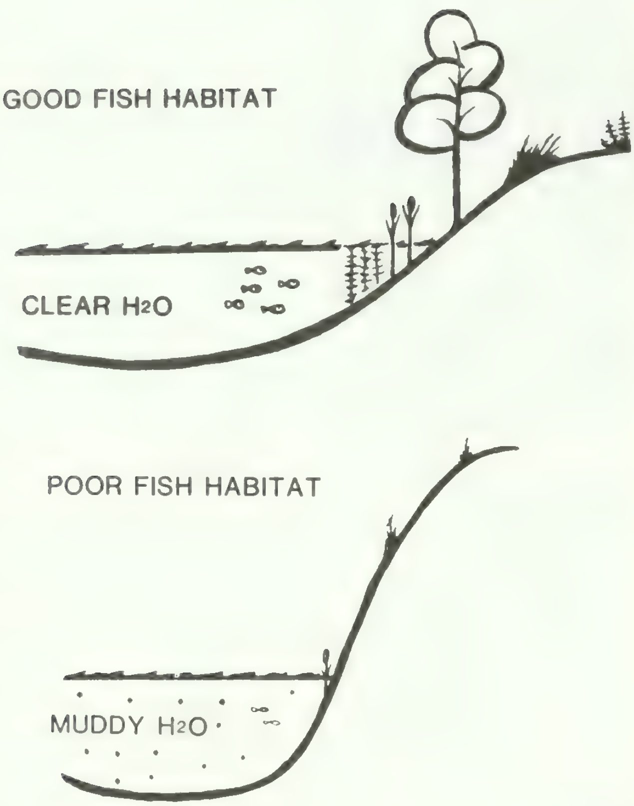

Figure 5.—Gentle slopes lead to clearer water, more shoreline vegetation, better fish habitat.

a pond (fig.5) and indirectly slows fish growth (Hawkes 1978). Turbidity is high in many bentonite surface mine impoundments due to the colloidal properties of the sediments. Steep slopes of surrounding spoil materials erode easily and contribute to high turbidity in impoundments. Scalet and Modde (1984) recommended that shoreline banks be sloped to a 3:1 ratio. Replacement of topsoil and re-establishment of vegetation on shorelines and adjacent spoil banks can reduce the high turbidities found in many existing surface mine impoundments.

Conclusions

Many surface mine impoundments in the northern High Plains can be modified to provide desirable and unique fish and wildlife habitats by following current reclamation laws and incorporating features that have characteristics important to targeted wildlife and/or fish species. Management criteria established for livestock impoundments are applicable for reclamation of surface mine impoundments. The planning and construction of new surface mine impoundments in surface mine operations should be encouraged to enhance the diversity of habitats for fish and wildlife in this semiarid region.

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Unreclaimed surface mine impoundments provide poor fish and wildlife habitat. Recommendations given here for reclaiming "prelaw" impoundments and creating new impoundments could provide valuable fish and wildlife habitat if incorporated into existing laws and mine plans.

Keywords: Surface mine impoundments, fish habitat, wildlife habitat, reclamation

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